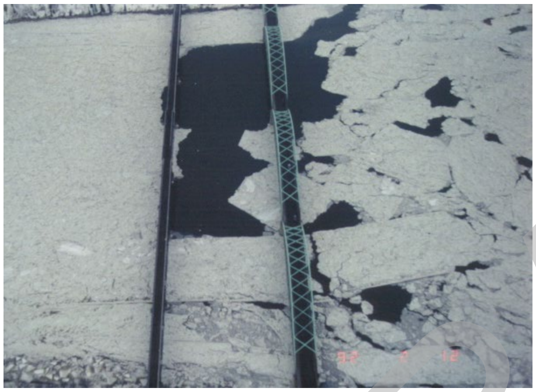
PEACE RIVER HAZARD STUDY

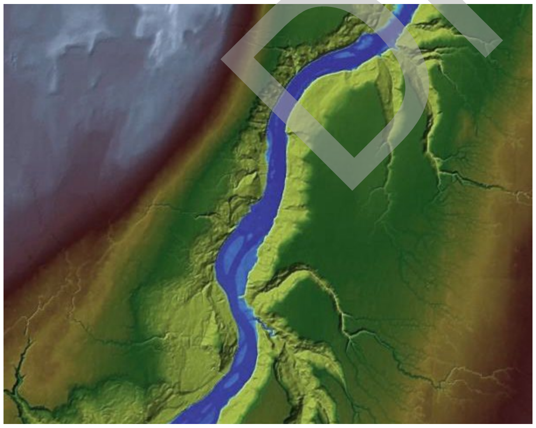
HYDRAULIC MODEL CREATION AND CALIBRATION

FINAL REPORT



Prepared for:

Alberta Environment and Parks



3 August 2017

(Revised 30 December 2019)

NHC Ref. No. 1001119

northwest hydraulic consultants
water resource specialists

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Alberta Environment and Parks
Edmonton, Alberta

Prepared by:

Northwest Hydraulic Consultants Ltd.
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APEGA Permit to Practice - P654

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DISCLAIMER

EXECUTIVE SUMMARY

Northwest Hydraulic Consultants Ltd. was retained in September 2015 by Alberta Environment and Parks to conduct a River Hazard Study for the Peace River through the Town of Peace River. The objectives of this River Hazard Study are to identify and assess river and flood-related hazards along 54 km of the Peace River, from about 6 km upstream of Shaftesbury Ferry to about 5 km downstream of the Highway 986 bridge, and along 1.2 km of the Heart River upstream of its confluence with the Peace River.

The Peace River Hazard Study has been structured into nine major project components. This report summarizes the work of the third component, *Hydraulic Model Creation and Calibration*. Pertinent flood history, a summary of available data, and description of physical features modelled are also provided for background information.

The June 1990 flood event, having an estimated peak discharge of 18,545 m^3/s at the Town of Peace River, was used to calibrate the hydraulic model. This event was the largest recorded flood and the most well-documented flood in terms of highwater marks available along the study reach to support model calibration. Water levels simulated by the calibrated model were within 0.01 m of the observed highwater marks on average for 37 separate locations along the study reach, with the greatest differences being 0.31 m below and 0.58 m above the observed highwater mark elevations. Model calibration was further informed by comparing the simulated stage-discharge rating curve at the Town of Peace River to the gauge rating curve published by the Water Survey of Canada at the same location. This comparison provided a basis for varying roughness parameters with discharge, as necessary and appropriate, such that the simulated water surface elevations were calibrated for the full range of discharges of interest.

A total of 13 flood frequency return periods were analyzed with the calibrated model, with simulated water surface profiles prepared for each event. The results indicate that the road and rail deck elevations for bridges crossing the Peace River are well above the 1000-year flood level, with the bottom chord for the left and right portions of the CPR bridge being the lowest, just above the 500-year open water flood level. On the Heart River, the 101 Street bridge is the lowest structure, with the base of the girders being just above the 10-year Peace River flood level. The crest of the flood control dykes on both the east and west side of the Peace River through the Town of Peace River generally sit about 0.95 m above the 100-year open water flood level. Results indicate that the Peace River flood control dykes would overtop at multiple locations for the 200-year and larger flood events.

As at the time of writing of this report, the calibrated open water model includes all pertinent physical features, flood control structures, and the most up-to-date bathymetry and terrain data available for the study area. Based on the results of the model calibration and comparison to the available data, the model presented herein is considered appropriate for use in the subsequent open water inundation mapping and flood hazard identification components of this Peace River Hazard Study.

CREDITS AND ACKNOWLEDGEMENTS

Northwest Hydraulic Consultants Ltd. would like to express appreciation to Alberta Environment and Parks (AEP) for initiating this project and making extensive background information available. The ongoing support and technical feedback from the AEP River Engineering and Technical Section team has been greatly appreciated throughout the project. In particular, the project team would like to thank representatives from the Town of Peace River that provided or assisted in the collection of historical data and other information to support this study. Also, we would like to acknowledge the contributions of data from Alberta Transportation associated with flood history and bridge information.

Project Managers for AEP were Nadia Kovachis Watson and Adam Minke. The following NHC personnel were part of the study team and participated in the hydraulic model creation and calibration component of the study:

- Dan Healy (Project Manager) – ensured the overall direction of the project and constructed the preliminary georeferenced hydraulic model.
- Robyn Andrishak (Hydraulic Modelling Lead) – Authored this report and was responsible for final development and calibration of the open water hydraulic model.
- Michael Brayall (Project Engineer) – was involved in compiling and analysed flood information and assisted in calibration of the open water hydraulic model.
- Dave Andres and Gary Van Der Vinne (Senior Technical Reviewers) – provided extensive senior review input and advice throughout the model construction and calibration work.

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1 INTRODUCTION

1.1 Study Objectives

The overall objectives of the Peace River Hazard Study are to identify and assess river and flood hazards along the Peace and Heart rivers through the Town of Peace River (TPR). The study is being completed 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 intent is to reduce potential future flood damage and disaster assistance costs to the federal, provincial, and local governments, including First Nations. New floodplain maps will inform land use planning decisions, assist with developing flood mitigation options and facilitate emergency response planning.

The Peace River Hazard Study has been structured into the following major project components.

1) Survey and Base Data Collection
2) Open Water Hydrology Assessment
3) Hydraulic Model Creation and Calibration
4) Open Water Flood Inundation Map Production
5) Open Water Flood Hazard Identification
6) Ice Jam Modelling Assessment and Flood Hazard Identification
7) Governing Design Flood Hazard Map Production
8) Flood Risk Assessment and Inventory
9) Channel Stability Investigation

This report summarizes the work of the third component – ***Hydraulic Model Creation and Calibration***. The primary tasks, services, and deliverables associated with this report are:

- Documentation of open water flood history.
- Creation, calibration, and validation of a HEC-RAS hydraulic model.
- Simulation of selected return-period floods and creation of water surface profiles throughout the study reach.
- A sensitivity analysis of the model inputs.

The development of the hydraulic model is foundational to the overall study and is required for the open water and ice jam flood inundation mapping as well as identification of flood hazard areas along the study reach.

1.2 Study Area and Reach

The Peace River flows into northwestern Alberta from British Columbia, passing through TPR, which is located about 380 km northwest of Edmonton. The extent of the contributing basin for the study reach is shown in **Figure 1**. Peace River flows are regulated by BC Hydro for hydropower production at Bennett Dam and Peace Canyon (PCN) Dam. The primary storage unit that enables regulation is Williston Lake, the reservoir created by Bennett Dam, which has sufficient capacity to provide multi-year storage of inflows.

The study reach consists of a 54 km segment of the Peace River beginning at the west boundary of 1-82-24-W5M about 6 km upstream of the Shaftesbury Ferry crossing (Highway 740) to the north boundary of 24-85-21-W5M about 5 km downstream of the Highway 986 bridge. The location of the study reach is shown in **Figure 1.** TPR is the most developed and populated area along this reach of the Peace River. Also included in the study area is a 1.2 km reach of the Heart River upstream of its confluence with the Peace River and a limited reach of the Smoky River near its confluence with the Peace River. Study limits are shown in **Figure 2**.

2 FLOOD HISTORY

2.1 General Information

Severe flooding has occurred on the Peace River, impacting mainly the TPR, which is situated low in the Peace River valley. A detailed description of local flood history has been prepared to provide context for the hydraulic model creation and calibration efforts. This flood history documentation includes both open water and ice jam related flooding that has been documented and observed. Available photo documentation from historic and recorded floods are provided in **Appendix A.**

2.2 Open Water Floods

Open water floods in the study area can arise as a result of high flows originating from the W.A.C. Bennett and Peace Canyon Dams, extreme summer rainfall events over the Smoky River basin, or a combination of both. Flood peak discharge magnitudes originating from the Smoky River can be of comparable size to those originating on the Peace River above the Smoky River. Open water floods on these rivers are most likely to occur in the months of June, July, or August.

2.2.1 Historic and Observed Open Water Floods

Historic floods refer to major floods that occurred prior to the period of hydrometric data collection and systematic recording of water level and discharge. In some cases, the magnitude of a historic flood can be estimated based on observations or even anecdotal information.

The Peace River at TPR and the Smoky River at Watino were gauged as early as 1917 and 1915, respectively. There are gaps in the data record for Peace River at Peace River between 1931-1957 and for the Smoky River at Watino between 1922-1954. During the gap for the Peace River there are records for three historic floods: these occurred in 1914, 1935 and 1948.

There are some historical flood observations for the Heart River and Pat's Creek, both tributaries to the Peace River that run through the TPR downtown area. The Heart River was gauged at TPR from 1915 to 1921 and then near Nampa, Alberta from 1963 to present. It should be noted that in some historical records the Heart River was identified as the Harmon River. No systematic hydrometric record exists for Pat's Creek at the time of this study.

The available historic observations are summarized in **Table 1**. There are insufficient details on discharges and water levels to use these historic flood data for model calibration.

Table 1 Historic and observed open water floods in the study area

Watercourse	Date	Details
Pat's Creek	2 July 1935	After several days of heavy rainfall, Pat's Creek overtopped its banks flooding Main Street in TPR (see **Figure A-1**, Appendix A). The floodwaters were laden with debris. Efforts were made by locals to sandbag downtown. The bridge pilings washed out on the railway bridge. Water began receding on July 5th, $500,000 of flood damage occurred in TPR.[1]
	27 June 2013	Extensive rain and debris blocking the culvert in Pat's Creek resulted in high water levels and flooding (see **Figure A-2**, Appendix A).[2]
Heart River	1913	A flood damaged the bridge and carried rock protection away, scouring enough to potentially expose the bedrock.[3]
	1914	A flood carried the Heart River bridge away[4] (see **Figure A-3**, Appendix A). It is not clear if the flooding was due to backwater effects from the Peace River.
	1923	High water levels on Heart River in Northern Sunrise County (see **Figure A-4**, Appendix A).[5]
	1933	Flooding on Heart River.[4]
	3 July 1935	Heavy rain resulted in flooding on the Heart River.[6]
	30 May 1948	Flooding on the Heart (Harmon) River.[7] It is not clear if flooding was due to backwater effects from the Peace River or high flows.
	1956	In 1956 a flood washed out the Heart River bridge.[4]
Smoky River	3 July 1935	The Smoky River at Watino reached its highest level in known history and part of the village of Watino was underwater.[6] The railway bridge was damaged and both approaches were partially washed out. An instantaneous peak discharge of [7,080 m^3/s] was estimated based on high water marks recalled by local inhabitants.[8]
	1954	A peak instantaneous discharge of [6,370 m^3/s] was estimated based on high water marks recalled by local residents.[8]
Peace River	1914	A severe flood created problems for the community of Peace River Crossing.[9] (see **Figure A-5**, Appendix A)
	3 July 1935	The Peace River rose more than 20 feet above the normal highwater mark and backwater effects caused the Heart River to flood main street with over three feet of water. The peak water level reached several inches above the floor of the Peace River creamery. (see **Figure A-6**, Appendix A) Peak instantaneous flows on the Peace River were estimated at [17,000 m^3/s] based on information obtained from local residents.[8]
	30 May 1948	A [335 m] long, [1.2 m] high dike was erected in Peace River; several families in West Peace River were flooded out and others in the town left their homes.[7]

Table 1 Historic and observed open water floods in the study area (continued)

Notes:

1. Norm Brownlee, Peace River Record Gazette. (21 Oct 2010). Pat's Creek saga runs through Peace River's history. Accessed from: http://www.prrecordgazette.com/2010/10/21/pats-creek-saga-runs-through-peace-rivers-history
2. Edmonton Sun. (8 April 2014). Peace River flooding downtown forces evacuation. Accessed from: http://www.edmontonsun.com/2014/04/08/peace-river-flooding-downtown-forces-evacuation
3. Alberta Transportation, Bridge File 2010-1913, Heart River Bridge.
4. Alberta Transportation. Bridge File 2010, Heart River Bridge.
5. Peace River Museum and Archives / Mackenzie Centre
6. The Montreal Gazette. (5 July 1935). Floods Subside Leaving 3 Dead.
7. The Montreal Gazette. (31 May 1948). Town of Peace River Facing Flood Menace.
8. Warner, L.A. and Thompson, W.C. (1974). Flood of June 1972 in the Southern Peace (Smoky River) Basin, Alberta. Technical Bulletin No. 87. Environment Canada. Inland Waters Directorate, Water Resources Brach, Calgary, Alberta.
9. Virtual Museum of Canada. (2016). Peace River, 1780-1914: From Athabasca to the Last Great West. Accessed from: http://www.virtualmuseum.ca/sgc-cms/histoires_de_chez_nous-community_memories/pm_v2.php?id=record_detail&fl=0&lg=English&ex=00000387&hs=0&rd=96536#

2.2.2 Recent and Recorded Open Water Floods

Table 2 summarizes the recent and recorded open water floods pertinent to the study area. Five recorded open water flood events are of interest and have sufficient available corroborating observed water levels to support the model calibration: 1972, 1990, 2001, 2011, and 2012. Note that ice jam floods, rather than open water floods, have been associated with the highest observed water levels on the Peace River. These events are discussed further in **Section 2.3**.

The WSC gauge at Dunvegan Bridge (Station 07FD003) provides the best estimate of flows on the Peace River above the Smoky River; the WSC gauge at TPR (Station 07HA001) provides a relatively complete and long-term record of flows downstream of the Heart River to the end of the study reach. The Smoky River is not gauged near the mouth, and this introduces some uncertainties when determining the magnitude and corresponding timing of flood peaks entering the Peace River from this tributary within the study reach. **Table 3** lists the recorded flood peak discharges for the five years of record with open water floods on the Peace River. Salient information describing each recent and recorded flood event is provided in the sections that follow.

Table 2 Recent and recorded open water floods observations in the study area

Watercourse	Date	Details
Heart River	14 June 1972	Flooding due to backwater effects from Peace River.[1,2] (see **Figure A-7**, Appendix A)
	14-15 June 1990	Heart River flooded due to backwater effects from the Peace River.[2] (see **Figure A-8**, Appendix A)
	11-12 July 2011	Water levels at the Heart River bridge were observed at 1.22 m below the bottom flange, but measurements were taken when the Peace River was 0.52 m below the event peak.[3]
Smoky River	14 June 1972	The Northern Alberta Railway Bridge at Watino was destroyed and damages were approximately $100,000.[1] (see **Figure A-9**, Appendix A)
Peace River	1965	The peak river level was [0.6 m] below the 1972 level.[4]
	14 June 1972	Worst flood ever recorded [to date]. At its peak the river was at a level of [13.1 m]. There was $200,000 of damage done to TPR and 105 people had to be evacuated.[4] (see **Figure A-10**, Appendix A)
	13-14 June 1990	Flood in June 1990 resulted in drift on bridge piers, bank slumping, loss of fill above culverts and some flooding.[5] (see **Figure A-11**, Appendix A)
	July 2011	High water levels, debris floating in River.[6] (see **Figure A-12**, Appendix A)

Notes:

1. Warner, L.A. and Thompson, W.C. (1974). Flood of June 1972 in the Southern Peace (Smoky River) Basin, Alberta. Technical Bulletin No. 87. Environment Canada. Inland Waters Directorate, Water Resources Brach, Calgary, Alberta.
2. Alberta Transportation. Bridge Files 2010 and 2010-1990, Heart River Bridge.
3. Alberta Transportation. Bridge File 2010-2011, Heart River Bridge.
4. Nelson, Dave (1972). Flood Peace River 1972. Valley Printers. Peace River Museum and Archives / Mackenzie Centre Item Number FC 3693.
5. Alberta Transportation. Bridge File 75946-1990, Highway 2 Bridge.
6. Alberta Transportation. Bridge File 75946-2011, Highway 2 Bridge.

Table 3 Associated peak discharges published by Water Survey of Canada for recent and recorded open water floods on the Peace River

Year	Flood peak discharge (m^3/s) on date and time indicated			
	Peace River at Dunvegan Bridge	Peace River at Town of Peace River	Smoky River at Watino	Heart River near Nampa
1972	N/A	15,600 14 Jun 15:00	9,200 14 Jun 05:00	1.05 (D) 15 Jun
1990	7,837 13 Jun 20:00	18,545 13 Jun 22:00	9,400 (E) 13 Jun 13:00	73.2 13 Jun 16:30
2001	6,120 22 Jul 10:45	10,000 22 Jul 20:30	4,290 19 Jul 19:05	2.55 21 Jul 8:00
2011	5,229 10 Jul 23:16	13,700 11 Jul 06:00	4,560 (E) 12 Jul 05:45	12.6 (D) 12 Jul
2012	6,200 9 Jun 18:01	8,970 (E) 10 Jun 03:45	2,540 8 Jun 07:00	6.28 10 Jun 01:01

Notes: (D) indicates peak is mean daily; (E) represents an estimated or suspect value in the reported record. All other values are peak instantaneous discharge.

1972 Flood

At the time, the June 1972 flood was the largest recorded flood on the Peace River at Peace River and the largest flood since the 1935 event. This flood resulted from concurrent events on the Smoky and Peace rivers. In a 36-hour period between 06:00 on 11 June and 18:00 on 12 June more than six inches (150 mm) of rain fell over parts of the Peace River basin southwest of Grande Prairie (Warner and Thompson, 1974). WSC published a peak instantaneous flow at TPR of 15,600 m^3/s at 15:00 on 14 June. This recorded gauge height for this event was 12.899 m (Warner and Thompson, 1974). The maximum gauge height of 10.132 m on the Smoky River at Watino occurred at 03:00 on the same date.

Although flow records from WSC of Canada indicate relatively low flows in the Heart River, water levels in the Heart River reached the low chord of the bridge on 101 Street due to backwater effects from the Peace River (Alberta Transportation, Bridge File 2010-1972). This flood event caused devastating flooding, in particular upstream in the basin near the Grande Prairie area where damage was estimated in excess of $1 million and on the Smoky River near Watino where damages to Alberta Resource Railway were estimated to exceed $8 million (Warner and Thompson, 1974). In the town of Peace River, more than 1.5 m of water was reported in West Peace River and 105 persons had to be evacuated.

1990 Flood

The June 1990 flood on the Peace River at Peace River is the largest recorded flood, having a peak instantaneous flow at TPR of 18,545 m^3/s at 22:00 on 13 June. This flood was the result of concurrent highwater events on the Peace River and Smoky River. This flood occurred during construction of the Highway 986 Bridge and caused substantial flooding to the staging area and overtopped and damaged the cofferdams (Alberta Transportation, File 81239-1990). At the Highway 986 bridge the high water level for this event reached 315.3 m. A high water mark of 317.78 m was surveyed by Alberta Transportation at the Highway 2 bridge in TPR (Bridge File 75946-1990).

Flooding was also reported in TPR along the Heart River. However, this flooding was related primarily to backwater effects from the Peace River flood, not to the magnitude of the peak discharge on the Heart River.

2001 Highwater Event

The Peace River peaked at approximately 10,000 m^3/s on 22 July 2001 through TPR. The magnitude of this event was not high enough to generate overbank flooding in the study area. Nevertheless, this event was included as a highwater event that could provide additional validation of the calibrated open water hydraulic model.

2011 Highwater Event

On 11 July 2011, the Peace River peaked at approximately 13,700 m^3/s through TPR. During this event, water rose to within 1 m of the bottom chord of the Heart River Bridge in town, but the event was not severe enough to cause flooding. This event was also included for additional validation of the calibrated open water hydraulic model.

2012 Highwater Event

Highwater on 10 June 2012 originated primarily from the upper Peace River with only a minor contribution coming from the Smoky River. The peak discharge through TPR of 8,970 m^3/s was lower than the 2001 and 2011 events, but included as additional model validation.

2.3 Ice Affected Floods

A number of ice affected floods have occurred in the study area, and ice jams are a significant component of the flood hazard at TPR. In particular, the Heart River and Smoky River are susceptible to flooding when they experience breakup before ice-out on the Peace River, which can lead to an ice jam forming at their confluences with the Peace River. The most severe ice affected flood impacts to people and property have typically occurred due to ice jams on the Peace River at TPR. Breakup on the Heart River has also contributed to flooding of low-lying areas, independent of breakup on the Peace River. As for open water floods, highwater induced by ice jams on the Peace River can result in flooding along the Heart River within TPR due to backwater effects, even if the discharge on the Heart River is minimal.

Flood history documentation for ice affected floods is provided in Section 2.2 and 2.3. of the ***Ice Jam Modelling Assessment & Flood Hazard Identification*** study component report.

3 AVAILABLE DATA

Other data pertinent to development of a calibrated hydraulic model includes basin hydrology, current high-resolution terrain data representing the floodplain, existing models, highwater marks, gauge data and rating curves, and flood photographs. The data available for this study is summarized below.

3.1 Hydrology Summary

An open water hydrology assessment of the Peace River was conducted as part the Peace River Hazard Study (refer to the ***Open Water Hydrology Assessment*** report provided under separate cover), which included estimates for both regulated and naturalized flows on the Peace River. The hydraulic model was divided into three reaches of interest where flood frequency estimates were available from the hydrology assessment:

- Peace River above the Smoky River confluence.
- Peace River below the Smoky River Confluence.
- Heart River at the mouth.

Table 4 summarizes the naturalized flood frequency discharges from the 2- to 1000-year floods, with associated probabilities of exceedance in any given year indicated.

Table 4 Naturalized flood frequency discharge estimates for the Peace and Heart rivers

Return Period (Years)	Probability of Exceedance in Any Given Year (%)	Naturalized Flood Frequency Discharge (m^3/s)		
		Peace River above Smoky River Confluence	Peace River below Smoky River Confluence	Heart River at the Mouth
1,000	0.10	19,600	31,600	317
750	0.13	19,000	30,100	305
500	0.20	18,200	28,100	289
350	0.29	17,500	26,400	274
200	0.50	16,500	23,900	252
100	1.0	15,200	21,100	224
75	1.3	14,700	20,100	212
50	2.0	13,900	18,600	195
35	2.9	13,300	17,400	180
20	5.0	12,300	15,600	157
10	10	11,100	13,500	127
5	20	9,770	11,600	96
2	50	7,850	9,050	49

Regulated flood peaks were not used when generating water surface profiles for the study in accordance with the terms of reference and FHIP guidelines. The Log-Pearson III distribution was used to define the flood frequencies on the Peace River and the Pearson III distribution was used on the Heart River.

3.2 Digital Terrain Model Data

A digital terrain model (DTM) based on airborne LiDAR data was supplied by AEP for this study. The DTM was based on data collected by Airborne Imaging on 7 October 2015 (Airborne Imaging, 2016). A complete description of the digital terrain model data and its comparison to the ground survey data is provided in Section 4.1 of the ***Survey and Base Data Collection Report*** provided under separate cover.

3.3 Survey Data

The development of the hydraulic model required extensive surveys of the river cross sections, bridges, and flood control dykes. Control points were also established to validate the DTM and facilitate the extension of the river cross sections through the overbank beyond the expected flood inundation limits. The survey program was conducted in the fall of 2015 and is documented in the ***Survey and Base Data Collection Report*** submitted as part of this study. A supplemental survey was conducted in September 2016 to collect additional cross sections, bridge geometry verification points, and highwater mark elevations.

A total of 81 cross sections were surveyed: 54 on the Peace River and 27 on the Heart River. The cross section locations were selected to capture changes in key hydraulic parameters such as the width and depth and at the location of islands. The mean cross section spacing was 1,022 m and 45 m on the Peace and Heart rivers, respectively.

To accurately model road and rail bridges, cross sections were surveyed immediately upstream and downstream of the bridge faces. Additional cross sections were surveyed one channel width upstream and downstream of the bridge faces to measure the shape of the cross section beyond the hydraulic influence of the bridge structure. For pedestrian bridges, one cross section was surveyed at the upstream side of the structure. Bridge geometric details were derived both from survey data and information from available bridge design drawings.

3.4 Existing Hydraulic Models

Several hydraulic models have been previously developed for the Peace River, with some of these being designed to support hydroelectric operational needs and studies to better understand the downstream effects of river flow regulation. The existing models focus on coarse hydraulic parameters along the entire length of the river and do not provide detailed information of flow conditions through TPR. As such, no existing models were used in the development or calibration of the hydraulic model for this study.

For informational purposes, the existing models are summarized as follows:

- BC Hydro maintains a HEC-RAS model of the Peace River that covers the reach from the Peace Canyon Dam to the confluence with the Slave River. The channel geometry is based on a large number of cross sections of varying quality that were surveyed along the Peace River by a number of agencies over the past 30 years or so. The model has been used for a number of major projects and studies completed by BC Hydro (2002, 2012) and Glacier Power Ltd. (NHC, 2006).
- The University of Alberta has developed hydraulic flood routing models for the Peace River using River1D (Hicks, 1996; Andrishak and Hicks, 2008). These models have been applied to investigate streamflow regulation impacts, climate change impacts on the river ice regime, and transboundary water scenarios. River geometry is typically based on limited survey data and rectangular channel sections. Their applicability is mainly for dynamic routing of flood waves or continuous, long-term simulations over time. Water levels tend not to be accurately represented by these models unless corrected by a known stage-discharge relationship at a gauging station.

3.5 Highwater Marks

Highwater mark observations provide documentation of the peak water levels that occurred at a given location for a particular flood of interest. These data are used for hydraulic model calibration and validation by comparing simulated water levels to the observed highwater mark elevations along the study reach. For this study, open water highwater marks were found in records from WSC and the Government of Alberta for the years 1972, 1990, 2011, and 2012. Additional highwater marks were obtained by TPR for a June 2016 high flow event on the Heart River that was not concurrent with a flood on the Peace River. Previous highwater marks along the Heart River that were documented were all representative of floods on the Peace River; therefore, due to the backwater effects, these data were not useful for calibration of the Heart River open water model reach.

Observed highwater mark data were available at the locations shown in **Figure 3A and B**. Data were not available at each indicated location for every event. **Table 5** provides a summary of the open water highwater mark data.

Table 5 Summary of open water highwater marks

Location Name	Upstream Cross Section	Distance from Cross Section (m)	Event Date	Highwater Mark Elevation (m)
Peace River				
Shaftsbury Ferry	XS #50	3	14 June 1990	323.93
Simpson's Residence	XS #46	4	14 June 1990	323.17
Mackenzie Cairn	XS #44	5	14 June 1990	322.76
Correctional Centre	XS #42	6	14 June 1990 22 July 2001 10 June 2012	322.40 320.10 319.66
Purcell's	XS #41	5	14 June 1990	322.15
Old Highway	XS #40	781	14 June 1990	322.00
Macleod Cairn	XS #39	6	14 June 1990	322.06
Power Pole	XS #39	176	14 June 1990	322.01
Gravel Pit	XS #38	1307	14 June 1990	321.60
Sawchuk's	XS #36	6	14 June 1990	320.72
109 Avenue West Peace	XS #32	176	14 June 1972	316.51
West Peace Boat Launch	XS #31	5	14 June 1990	319.71
Heart River at Museum	XS #31	44	14 June 1990	319.66
West Peace North End	XS #30	16	14 June 1990	319.40 (LB) 319.66 (RB)
Pat's Creek	XS #30	305	14 June 1972 11 July 2011	316.51 317.04 (E)
W.H.Wood's	XS #30	663	14 June 1990	319.11
Rail Bridge	XS #27	5	14 June 1990	318.83
Hwy 2 Bridge	XS #24	6	13 June 1990 14 June 1990 11 July 2011	317.79 318.61 317.91
WSC Gauge (07HA001)	XS #22	6	14 June 1990 14 June 1972 22 July 2001 11 July 2011 10 June 2012	318.69 315.59 315.66 317.04 314.95
Bewley Island 2	XS #21	5	14 June 1990	318.61
Czuy's House	XS #19	133	14 June 1990	318.34
Centre of Lee Island	XS #19	1167	14 June 1972	315.04
Dick's Diving	XS #17	5	14 June 1990	317.93

Table 5 Summary of open water highwater marks (continued)

Location Name	Upstream Cross Section	Distance from Cross Section (m)	Event Date	Highwater Mark Elevation (m)
Peace River				
Six Mile Farm	XS #15	669	14 June 1990	316.76
Birch Island	XS #09	5	14 June 1990	315.21
Daishowa Bridge (Highway 986)	XS #06	5	13 June 1990 14 June 1990	315.30 315.60
Daishowa Intake	XS #05	4	14 June 1990	314.30
Shell Intake	XS #03	817	14 June 1990	313.53
Heart River				
Stake 4	XS #67	12	3 June 2016 20 June 2016	314.61 314.84
Stake 3	XS #64	28	3 June 2016 20 June 2016	313.93 314.61
Stake 2	XS #61	27	3 June 2016	313.09
101 Street Bridge	XS #60	1	13 June 1990 11 July 2011	318.00 317.78

3.6 Gauge Data and Rating Curves

Water level (stage) records and rating curves from WSC hydrometric gauging stations in and around the study area were obtained and used support creation and calibration of the hydraulic model. **Table 6** lists the gauging stations for which data were examined and their respective periods of record.

Table 6 List of hydrometric gauges supporting model creation and calibration

Type	Station ID	Station Name	Period of Record
Discharge	07HA001	Peace River at Peace River	1915-1930, 1958-present
	07FD003	Peace River at Dunvegan Bridge	1960-1969, 1975-present
	07GJ001	Smoky River at Watino	1915-1922, 1955-present
	07HA003	Heart River near Nampa	1963-present
Water Level	07FD901	Peace River above Smoky River Confluence	2000-present

One WSC gauging station, 07HA001 – Peace River at Peace River, was located within the study area. The two most recent rating curves and the associated discharge measurements used to derive the curves for this station are shown in **Figure 4**. Rating curve #11 has been in use since November 2006 while curve

#10 was issued in October 1990, after the June 1990 flood peak estimate was included in the analysis. Curve #10 was used for the open water hydraulic model calibration since it was the one considered most applicable for the calibration event. As seen in the figure, curves #10 and #11 are not substantially different, with curve #10 indicating slightly lower stages for discharges below 1,700 m^3/s. Another feature of note is that the discharge measurements from which the rating curves were developed range from 750 up to 9,490 m^3/s; no discharge measurements are available above 10,000 m^3/s. Note that 9,490 m^3/s was associated with the July 1972 flood event. An additional water level recording station, 07FD901 – Peace River above Smoky River Confluence, is located within the study area. However, due to this station's proximity to the Smoky River confluence, no unique stage-discharge rating curve exists.

Gauge data from the other stations listed in **Table 6** were also used to estimate flood event discharges along the study reach for model calibration. In determining the recorded historical flood peak discharges applicable to various segments of the study reach and any observed event highwater marks, the hourly gauge data (or original strip charts) for Peace River at Peace River (07HA001), Peace River at Dunvegan Bridge (07FD003), Smoky River at Watino (07GJ001), and Heart River near Nampa (07HA003) were each examined. Also, time of travel from Watino to the mouth of the Smoky River, Nampa to the mouth of the Heart River, and Dunvegan to the upstream limit of the study area were considered when evaluating peak discharges for a recorded flood event.

For model calibration, the largest, well-documented event was the June 1990 flood, described earlier. The published stage hydrographs for this event are shown in **Figure 5.** Unfortunately, neither the station data nor a copy of the original strip chart for the Smoky River at Watino recorded the actual flood peak due to an equipment malfunction; therefore, data were not available for the period from 13 to 18 June 1990. WSC has published an estimated instantaneous peak discharge of 9,400 m^3/s occurring at 13:00 on 13 June at Watino based on observed highwater marks after the flood. The peak gauge heights at each gauge and the time that they occurred are summarized in **Table 7**.

Table 7 Summary of peak stage measurements and discharge estimates for the June 1990 flood

Station ID	Station Name	Time of Peak	Peak Water Level (m)	Top of Bank Elevation (m)	Peak Discharge (m^3/s)
07FD003	Peace River at Dunvegan Bridge	13 June 18:30	345.21	345[a]	7,830
07GJ001	Smoky River at Watino	13 June 13:00	384.07	382[a]	9,400
07HA003	Heart River Near Nampa	13 June 16:30	N/A	N/A	73.2
07HA001	Peace River at Peace River	13 June 22:00	318.69	320.6[b]	18,545

Notes:

a) Data from Trillium Engineering (1996)

b) Top of bank reported as crest of east dike elevation

An exercise was completed to determine an appropriate peak discharge for the Smoky River at the mouth to use in the model calibration. NHC's previous experience with dynamic flood routing on the

Peace River suggests that flood wave attenuation is minimal for waves travelling down the Peace River between the Dunvegan Bridge and Town of Peace River gauging stations and the time of travel between the two stations is approximately 10 hours. The Peace River at Peace River and Peace River at Dunvegan Bridge discharge hydrographs (adjusted for time of travel to Town of Peace River and assuming no attenuation of the peak) were used to estimate the June 1990 flood hydrograph for the Smoky River at the mouth and evaluate the sequence of peak discharges originating from the Peace and Smoky rivers. The Heart River discharge was assumed to be constant at its peak value for the purpose of this analysis. The resulting concurrent discharge hydrographs from this analysis are shown in **Figure 6**. The timing of the peaks suggests that the Smoky River peaked at the mouth approximately nine hours before the arrival of the peak from the Peace River above the confluence.

The peak discharge estimates in **Table 7** above based on extrapolations of the stage-discharge rating curve beyond the range of measured values, which introduces uncertainty in the accuracy of these estimates. The largest recorded discharge and the ratio of the June 1990 discharge estimate to this largest recorded discharge for the gauging stations of interest for the model calibration are provided in **Table 8**.

Table 8 Comparison of the June 1990 flood estimates to the largest measured discharges for the Peace and Smoky rivers

Station ID	Station Name	Largest Measured Discharge (m^3/s)	Ratio of June 1990 Flood Estimate to Largest Measurement
07FD003	Peace River at Dunvegan Bridge	6,040	1.30
07GJ001	Smoky River at Watino	4,280	2.20
07HA001	Peace River at Peace River	9,490	1.95

These results show that the June 1990 flood on the Peace River above the Smoky River exceeded the largest measurement by only 30%; the magnitude of the flood on the Smoky River and the peak captured at TPR exceeded the measurement range by a much larger margin. This implies that the greatest uncertainty exists in the flood peak estimate for the Smoky River. At TPR, there is believed to be comparable uncertainty in the estimate for Dunvegan, since the TPR flood control dykes were not overtopped for this event. (Had the flood control dykes overtopped, the peak discharge estimate at TPR based on gauged stage and the rating curve would have been more uncertain.) At Watino, the peak stage was approximately 2 m above the top of river bank at the gauge.

3.7 Flood Photography

Flood photography has been obtained from various sources including the Town of Peace River, Peace River Museum and Archives, Government of Alberta, Valley Printers, Peace River Record-Gazette and others. A compendium of these photographs documenting the local flood history is provided in Appendix A.

4 RIVER AND VALLEY FEATURES

4.1 General Description

The Peace River is partially entrenched and confined within a deep, stream-cut valley with occasional slumps. Terraces exist on two fragmentary levels within the 2 km wide valley. The Peace River valley is sparsely populated with the majority of development found at TPR. Further details regarding the river channel and valley features are provided below.

4.2 Channel Characteristics

The channel follows a sinuous planform pattern that is laterally-stable with occasional islands and mid-channel bars (Kellerhals et al, 1972). The reach-average channel slope is 0.00035 m/m. The channel bed material consists of gravel over soft cohesive (shale) bedrock; bank materials consist of gravel overlain by silt and moderately erodible rock (Kellerhals et al, 1972). Based on flow conditions at the time of the open water survey in October 2015, the average top width through the study reach was 470 m and the mean cross section depth was about 3.5 m at the mean annual discharge.

4.3 Floodplain Characteristics

The general terrain through this region of the Peace River valley consists of cultivated, partly built-up, and moderately forested plain on hummocky till (Kellerhals et al, 1972). Along most of the study reach, the floodplain is relatively narrow and confined by the steep valley walls. A broader, well-defined floodplain exists through TPR and near the Diashawa (DMI) pulp mill site.

4.4 Bridges, Culverts and Weirs

The Peace River in the study area is spanned by a total of three bridges; four bridges cross the Heart River in the study area. The bridge descriptions and locations with respect to the established river stationing are provided in **Table 9**.

Table 9 Bridges crossing the Peace and Heart rivers within the study area

Bridge Description	River Station (m)
CNR Bridge crossing Peace River	22109.1
Highway 2 Bridge crossing Peace River	22017.4
Highway 986 Bridge crossing Peace River	4905.4
CNR Bridge crossing Heart River	766.9
Pedestrian Bridge 1 crossing Heart River	453.6
101 Street Bridge crossing Heart River	180.3
Pedestrian Bridge 2 crossing Heart River	30.1

The three bridges crossing the Peace River each have multiple spans with piers in the channel. Three of the four bridges crossing the Hear River span the entire channel with no instream piers; the 101 Street Bridge crossing the Heart River is a two span structure with a mid-channel pier. Detailed information concerning the bridge configurations can be found in Appendix D of the ***Survey and Base Data Collection Report*** provided under separate cover.

Neither the Peace River nor the Heart River pass through any culverts or over any weirs or like structures within the study area.

4.5 Flood Control Structures

A system of flood control dykes was constructed at TPR after the open water flood of 1972. The extents of the flood control dykes are shown on **Figure 7**. The flood control dyke on the right (east) bank of the river protects a large portion of downtown TPR extending both upstream and downstream of the Highway 2 bridge, from the water treatment plant to 109 Avenue. Following the 1990 flood, the open guardrail on the Heart River Bridge in downtown Peace River was replaced with a solid concrete wall and integrated into the surrounding flood control dyke system that ties into high ground near the valley wall on both sides of the Heart River. The Lower West Peace neighbourhood is also enclosed by a flood control dyke along the left (west) bank of the Peace River.

A small earthen berm extends along the right bank of the Heart River through Twelve Foot Davis Park. Detailed records are not available for this structure, although it was likely constructed to provide some measure of flood protection for the park site.

4.6 Other Features

The majority of major infrastructure and populated areas within the study area are found at TPR. Other features of note within the Peace River valley include:

- The Shaftesbury Ferry crossing at river station 48294 m, which operates during the open water period, and the ice bridge, which operates in the same location when ice conditions are suitable.
- The Peace River Correctional Centre at river station 37240 m.
- Secondary Highway 684 from Shaftesbury Ferry to TPR along the west side of the Peace River.
- The DMI pulp mill at river station 4477 m on the west side of the Peace River, near the downstream study area limit.

5 MODEL CONSTRUCTION

5.1 HEC-RAS Program

The U.S. Army Corps of Engineers *Hydrologic Engineering Center-River Analysis System* (HEC-RAS) computer program (Version 5.0.1, April 2016) was used to calculate the flood levels along the study reach. The basic inputs required by HEC-RAS are a series of cross sections spaced over known lengths of channel, roughness coefficients for the channel and overbank areas at each cross section, a specified water level or slope at the downstream model boundary, and a discharge at all upstream model boundaries. In cases where supercritical or "mixed" flow regimes are encountered, a specified water level or slope is also required at each upstream boundary.

5.1.1 Theoretical Aspects

HEC-RAS applies the Bernoulli equation between consecutive cross sections and is designed to determine subcritical and/or supercritical water surface profiles; assess the hydraulic effects of channel and floodplain adjustments such as channel straightening, encroachment, enlargement, and flood control dyking; and estimate energy losses due to in-channel structures such as culverts, bridges, weirs, and other obstructions. The analytical approach employed by HEC-RAS has the following assumptions and potential limitations:

- Flow is gradually varied, so that the boundary friction losses between cross sections can be estimated by Manning's equation using section-average parameters.
- Changes in the channel and floodplain geometry resulting from erosion or mobile bed processes that might arise during a flood cannot be directly accounted for or modelled.
- The water level is constant across each cross section, with three separate conveyance components representing the main channel and each of the left and right overbank zones.
- Flow is one-dimensional, therefore only velocity components in the principal direction of flow are accounted for in the equations and calculations.

Simulation of overbank floodplain behind the Peace River flood control dykes challenges the assumption that the flow patterns are one-dimensional within the study reach. Care was taken to address this when developing the model geometry as discussed in **Section 5.2** below.

5.1.2 General Model Setup

Geometric Layout

General model setup, which included defining a river centerline profile alignment, laying out cross section cut lines, and locating bridges and flood control dykes within the study area, was completed in ESRI ArcGIS. The total reach length modelled was just over 54.1 km following the established centerline river profile. In addition, a 1.1 km reach of the Heart River above the confluence with the Peace River was included in the model. Cross section geometry was developed by combining surveyed channel cross section bathymetry and the DTM provided by AEP. The limits of each cross section were set such that they extended across the floodplain, beyond the 1000-year flood level. Near the confluence, the Heart River crosses the Peace River floodplain within TPR. Extension of the Heart River cross sections in this area required choosing alignments that provided a reasonable transition between water levels simulated on the Heart River and adjacent Peace River cross sections. The resulting alignments could not, in some circumstances, also concurrently satisfy the assumption of flow (in the overbank) perpendicular to the cross section. This was most notably the case for the left overbank portions of Heart River cross sections that are oriented, with respect to the Peace River, in the upstream direction.

The Heart River was not connected to the Peace River by means of a junction in HEC-RAS, as the assumptions used in the model formulation were determined to be invalid. Specifically, the junction formulation assumes that the energy grade lines (not the water surface elevations) are equal for upstream cross sections connected at a combining flow junction. At the confluence, the energy of the Heart River is significantly lower than the energy of the Peace River for flood conditions, so it would normally be appropriate to locate the most downstream cross section on the Heart River farther upstream, away from the region dominated by backwater from the Peace River. However, cross sections were required right up to the confluence for flood mapping purposes. Therefore, if these two reaches were connected using a junction, the model would produce artificially high water levels along the downstream portion of the Heart River. Since the Heart River was not connected to the Peace River through a junction, the water level at the downstream boundary of the Heart River was manually specified to match the corresponding water level in the Peace River for each simulation (see ***Boundary Conditions***, below).

All aspects of the HEC-RAS model geometric layout were geo-referenced using the 3TM NAD83 CSRS project coordinate system and HEC-GeoRAS utility developed by the U.S. Army Corps of Engineers for the ArcGIS platform. Refer to Section 2.1.1. of the ***Survey and Base Data Collection Report*** for more information concerning the reference coordinate system. Specifics regarding the model geometry are provided in **Section 5.2** below.

Channel and Overbank Roughness

Manning's roughness values were used throughout the modelled reaches. At each cross section, roughness was varied horizontally across the channel as required to represent changes in river and floodplain characteristics. A minimum of three (one channel and two overbank) and a maximum of eight (at XS #37) roughness values were used on each cross section, depending on the complexity of the channel and presence of distinct features such as islands. Manning's roughness is well-known to account for an array of energy losses in open channel flow computations that are not constant with respect to discharge, so as described further in **Section 5.4.1**, roughness values were set to vary with discharge according to a calibrated series of roughness change factors applied consistently across the entire model. It was advantageous to use this approach to facilitate development of a HEC-RAS model based on a single geometry specification that best represents the wide range of flood frequency discharges under consideration.

Boundary Conditions

Boundary conditions for the model included specified inflows at the upstream ends of the Peace and Heart rivers. Flow changes were also provided on the Peace River immediately downstream of the Smoky River and, for calibration events only, also below the Heart River confluence to account for additional inflows from each respective tributary at those locations. The downstream boundary on the Peace River was represented by a surveyed cross section approximately 860 m downstream of the study reach at the north boundary of 24-85-21-W5M.

A uniform flow or normal depth water level approximation was assigned to the Peace River downstream boundary. The choice of normal depth slope, S = 0.00025, was based on a reach-average energy grade line slope. This boundary condition provided simulated water levels that agreed well with observed water levels near the downstream boundary for a range of discharges and resulted in a normal flow depth condition being achieved at the downstream limit of the study area. A specified water level boundary was also required at the most downstream cross section (XS #55) on the Heart River. For each simulation, this value was taken as the average of the computed water levels at Peace River XS #30 and #31, which bracket the Heart River confluence. Computed Heart River downstream boundary condition values are provided in **Table 17** (Section 5.3.5) for the calibration events and **Table 22** (Section 5.5) for the flood frequency profiles.

5.2 Geometric Database

The geometric database provides all of the components of the HEC-RAS model geometry developed using the geospatial analysis tool within ArcGIS. The HEC-GeoRAS toolbox facilitated the development of the model geometry. Further processing of the data was performed using the HEC-RAS geometry editor. The following describes the content of the geometric database and methods for model geometry development. The resulting geometric database is provided as part of the electronic deliverables of the study.

5.2.1 Cross Section Data

Cross section alignments were established in ArcGIS following the general path of the topographic and hydrographic survey points for each of the 54 cross sections surveyed on the Peace River (refer to **Section 3.3**). A total of 27 surveyed cross sections were also established in the model for the Heart River through TPR.

Each cross section extends through the left and right overbanks up the valley wall to an elevation beyond the anticipated 1,000-year flood level. Cross section elevations were derived from a combination of the DTM data, the topographic survey data, and the hydrographic survey data as follows:

1. The cross section alignments were defined to pass through the surveyed point data and extended into the overbank above the anticipated 1000-year flood level.

2. Two separate station-elevation data sets were created for each cross section.

   a. The first was developed from elevation data extracted from the DTM using the GeoRAS ArcGIS extension tool.

   b. The second was based on the survey data and was developed by projecting the topographic and hydrographic survey points onto the cross section line in a direction perpendicular to alignment of the cross section line using the GeoRAS ArcGIS extension tool.

3. Both station-elevation data sets were exported from ArcGIS to a HEC-RAS geometry format.

4. The DTM-based and survey-based cross sections were combined in HEC-RAS using the Graphical Cross Section Editor. The number of elevation points in the combined cross sections were reduced to less than 500 using the minimize area change point filter option.

Distances between each cross section along the channel centerline and along the central flow path of the left and right overbank areas were measured in ArcGIS and exported with other cross section data to the HEC-RAS model. Cross section details based on NHC's surveys are provided in **Table 10**.

Table 10 Model cross section details

Cross Section	River Station (m)	Source data for Main Channel/Floodplain	Thalweg Elevation (m)	Channel Width (m)	Notes
Peace River					
XS #54	54139.1	survey/DTM	317.01	698.4	Upstream model limit
XS #53	52544.4	survey/DTM	316.17	518.8	
XS #52	50979.5	survey/DTM	314.48	511.0	
XS #51	49803.2	survey/DTM	314.72	481.4	
XS #50	48297.0	survey/DTM	313.23	396.9	Shaftesbury Ferry
XS #49	47054.7	survey/DTM	313.17	524.1	
XS #48	45563.6	survey/DTM	314.89	819.2	
XS #47	44051.3	survey/DTM	314.45	743.7	
XS #46	42705.2	survey/DTM	313.88	700.9	
XS #45	41405.6	survey/DTM	311.17	855.0	
XS #44	39966.2	survey/DTM	312.09	460.7	
XS #43	38663.5	survey/DTM	309.54	538.2	

Table 10 Model cross section details (continued)

Cross Section	River Station (m)	Source data for Main Channel/Floodplain	Thalweg Elevation (m)	Channel Width (m)	Notes
		Peace River			
XS #42	37246.3	survey/DTM	312.35	491.4	WSC Gauge 07FD091
XS #41	35284.7	survey/DTM	310.17	544.0	
XS #40	33566.0	survey/DTM	309.67	478.0	
XS #39	31899.6	survey/DTM	308.37	618.1	
XS #38	30757.8	survey/DTM	307.65	854.8	u/s Smoky River
XS #37	28861.6	survey/DTM	306.75	1304.8	d/s Smoky River
XS #36	28108.3	survey/DTM	310.19	904.2	
XS #35	27059.9	survey/DTM	309.46	983.3	
XS #34	26167.3	survey/DTM	307.81	1098.9	
XS #33	25065.3	survey/DTM	308.57	1017.9	
XS #32	24146.4	survey/DTM	307.11	527.9	Lower West Peace
XS #31	23492.6	survey/DTM	305.26	494.8	u/s Heart River / Upper West Peace
XS #30	23295.0	survey/DTM	305.05	486.7	d/s Heart River
XS #29	22393.0	survey/DTM	303.8	410.9	
XS #28	22118.1	survey/DTM	303.45	442.9	u/s CNR Bridge
XS #27	22100.7	survey/DTM	303.54	443.8	d/s CNR Bridge
XS #26	22063.8	survey/DTM	303.01	449.8	
XS #25	22027.4	survey/DTM	302.93	454.8	u/s Hwy 2 Bridge
XS #24	22007.4	survey/DTM	302.74	458.3	d/s Hwy 2 Bridge
XS #23	21736.0	survey/DTM	304.38	527.5	
XS #22	21329.3	survey/DTM	307.93	731.4	WSC Gauge 07HA001
XS #21	20902.1	survey/DTM	307.17	950.1	u/s Bewley Island
XS #20	20583.9	survey/DTM	306.04	1105.9	
XS #19	19733.3	survey/DTM	303.96	797.7	
XS #18	18523.1	survey/DTM	305.68	1349.1	d/s Bewley Island
XS #17	16963.1	survey/DTM	304.8	953.4	
XS #16	15681.7	survey/DTM	303.99	849.9	
XS #15	14591.1	survey/DTM	304.29	827.7	
XS #14	13053.2	survey/DTM	301.16	673.6	
XS #13	11809.6	survey/DTM	301.92	603.2	
XS #12	10385.1	survey/DTM	298.82	501.8	

Table 10 Model cross section details (continued)

Cross Section	River Station (m)	Source data for Main Channel/Floodplain	Thalweg Elevation (m)	Channel Width (m)	Notes
Peace River					
XS #11	9024.8	survey/DTM	302.44	543.2	
XS #10	7564.1	survey/DTM	301.16	906.9	
XS #09	6270.6	survey/DTM	299.1	491.3	
XS #08	5365.3	survey/DTM	299.42	599.5	
XS #07	4915.2	survey/DTM	296.79	521.7	
XS #06	4895.6	survey/DTM	298.69	510.0	Hwy 986 Bridge
XS #05	4480.9	survey/DTM	298.85	486.7	
XS #04	3709.0	survey/DTM	299.51	464.8	
XS #03	2382.4	survey/DTM	297.93	597.2	
XS #02	1302.7	survey/DTM	298.73	688.9	
XS #01	0.0	survey/DTM	295.79	373.4	Downstream model limit
Heart River					
XS #81	1165.6	survey/DTM	316.53	36.4	Upstream model limit
XS #80	1103.3	survey/DTM	316.98	41.2	
XS #79	1045.2	survey/DTM	316.97	54.7	
XS #78	977.4	survey/DTM	315.81	40.1	
XS #77	909.0	survey/DTM	316.05	31.7	
XS #76	860.2	survey/DTM	315.95	30.8	
XS #75	803.6	survey/DTM	315.44	33.2	
XS #74	774.8	survey/DTM	315.14	32.2	u/s CNR Bridge
XS #73	759.8	survey/DTM	315.05	30.8	d/s CNR Bridge
XS #72	719.6	survey/DTM	315.34	38.5	
XS #71	678.5	survey/DTM	315.31	42.7	
XS #70	624.3	survey/DTM	314.31	49.3	
XS #69	575.0	survey/DTM	314.22	34.4	
XS #68	529.0	survey/DTM	314.26	38.9	
XS #67	485.1	survey/DTM	313.68	38.9	
XS #66	458.7	survey/DTM	313.56	46.1	u/s Pedestrian Bridge
XS #65	427.5	survey/DTM	313.15	28.1	
XS #64	402.9	survey/DTM	313.25	30.3	
XS #63	353.8	survey/DTM	313.36	49.1	

Table 10 Model cross section details (continued)

Cross Section	River Station (m)	Source data for Main Channel/Floodplain	Thalweg Elevation (m)	Channel Width (m)	Notes
Heart River					
XS #62	292.4	survey/DTM	313.02	48.4	
XS #61	228.6	survey/DTM	312.58	45.5	
XS #60	189.6	survey/DTM	312.36	56.2	u/s 101 Street Bridge
XS #59	172.3	survey/DTM	312.64	55.0	d/s 101 Street Bridge
XS #58	130.7	survey/DTM	312.40	42.1	
XS #57	70.3	survey/DTM	311.89	45.5	
XS #56	41.6	survey/DTM	311.96	47.6	u/s Pedestrian Bridge
XS #55	0.0	survey/DTM	311.38	55.2	Mouth of river

5.2.2 Bridges, Culverts & Weirs

The modelled reach included two highway bridges and one rail bridge crossing the Peace River and one local road bridge, two pedestrian bridges, and one rail bridge crossing the Heart River. **Table 11** provides a summary of bridges included in the analysis and key design information incorporated into the model. There were no culverts or weirs to be modelled within the study area. Any existing culverts in the study area serviced local drainage only and are not relevant to the hydraulic model computations.

The alignment and location of each bridge structure was established in ArcGIS midway between surveyed cross sections bracketing the bridge. The bridge cross section line was assigned the same length as the bracketing cross sections to ensure that the stationing of the bridge cross section was consistent with the bracketing cross sections. The bridge cross section included the approach roadway on both banks, abutments, high and low chord defining the bridge structure, and the piers. The approach roadway was extracted from the DTM in ArcGIS while the bridge abutments, high and low chords, and piers were extracted from the surveyed data. Bridge details were checked against design drawings and details available Alberta Transportation bridge file records and other sources, where available.

For the two railway bridges, safe access to the structures could not be obtained to collect direct survey measurements. Bridge geometry was derived from the available general bridge layout and elevation drawings, the supplied DTM data, and orthorectified imagery. Some limited survey validation of the bridge structure elevations, and pier spacing dimensions was obtained using a total station.

Each of the three bridges over the Peace River were modelled using the highest energy solution of the energy, momentum, and Yarnell methods. These structures have similar triangular shaped pier nose and tail and were assigned a drag coefficient of 1.39 (for the momentum method) and a pier shape coefficient of 1.05 for the Yarnell method. The four bridges crossing the Heart River were limited to the standard energy solution method only. This was deemed necessary to accurately represent the effect of backwater (from the Peace River) along the Heart River reach.

Table 11 Description of bridges included in the hydraulic model

Description	Representative Cross Sections	Bridge File Number	Design Details
CNR Bridge crossing Peace River	XS #27 XS #28	N/A	560 m long, 13 span bridge with a width of 10.7 m and rail deck elevation from 334.8 to 334.9 m; lowest elevation of steel superstructure varies by span extending as low as 12.6 m below rail deck; concrete piers 4.0 m wide in-channel spaced 62.3 m apart.
Highway 2 Bridge crossing Peace River	XS #24 XS #25	BF75946	570.2 m long, eight span bridge with a deck width of 18.4 m and top of curb at elevations from 328.7 to 336.6 m; low chord of bridge is approximately 1.9 m below top of curb; concrete piers 4.5 m wide in-channel spaced 124 m apart.
Highway 986 Bridge crossing Peace River	XS #06 XS #07	BF81239	726.6 m long, seven span bridge with a deck width of 15.6 m and top of curb at elevations from 331.1 to 336.3 m; low chord of bridge is 5.2 m below top of curb; concrete piers 2.5 m wide spaced 112 m apart.
CNR Bridge crossing Heart River	XS #73 XS #74	N/A	190 m long steel trestle bridge with a width of 15 m and rail deck elevations from 358.4 to 359.6 m; low chord of bridge girders assumed to be 3 m below rail deck; eight solid vertical members of trestle represented as piers 1.25 m wide in pairs spaced 12 m apart on 15.3 m spans crossing the valley and 35.5 m crossing the river channel
Pedestrian Bridge 1	XS #66	N/A	55.9 m long single span steel truss bridge with a deck width of 2.5 m and elevation of 322.0 m; low chord of bridge is approximately 0.8 m below bridge deck.
101 Street Bridge	XS #59 XS #60	BF02010	60.0 m long, three span bridge, 17.0 m wide with solid concrete guard rails to elevations 321.1 to 321.4 m; low chord of bridge is 2.9 m below top of guard rail; piers are 0.7 m wide spaced 22.9 m apart.
Pedestrian Bridge 2	XS #56	N/A	51.0 m long single span steel arch bridge with a deck width of 2.5 m and elevation between 321.1 to 322.3 m; low chord of bridge is approximately 0.2 m below bridge deck.

5.2.3 Flood Control Structures

The top of flood control dyke profiles along the west and east side of Peace River were surveyed during the field program. These data, in conjunction with the DTM, were used to inform the specification of levees in the HEC-RAS model. Levees in HEC-RAS restrict the wetted portion of the channel to the area inside the levees until the simulated water level exceeds a specified elevation. Generally, the levee elevation corresponds to the crest elevation of the flood control dyke, above which overtopping occurs; however, consideration was given to overtopping points at adjacent upstream and downstream cross sections to ensure that when a levee is overtopped and water appears in the model behind the levee, connected areas also appear wet for the same simulated water surface profile. This process involved determining an effective levee elevation at some cross sections that is below the actual crest of the flood control dyke. The surveyed crest elevations and effective levee elevations for the east and west Peace River flood control dykes are provided in **Table 12** below.

Table 12 Modelled flood control structure details

Description	Cross section	Surveyed crest elevation (m)	Effective levee elevation (m)
Peace River East Dyke	XS #32	323.06	320.78
	XS #31	323.30	320.78
	XS #30	321.05	320.19
	XS #29	321.10	319.80
	XS #28	320.60	319.38
	XS #27	320.68	319.38
	XS #26	320.70	319.38
	XS #25	320.71	319.38
	XS #24	320.66	319.38
	XS #23	320.72	320.21
	XS #22	320.49	320.21
	XS #21	320.57	320.21
	XS #20	320.63	320.35
	XS #19	320.45	319.90
	XS #18	319.86	319.70
Peace River West Dyke	XS#33	328.71	322.37
	XS #32	321.83	321.78
	XS #31	321.21	321.21
	XS #30	321.05	321.01
12 Foot Davis Park Dyke	XS #71	320.57	319.40
	XS #70	319.96	319.40
	XS #69	319.74	319.40
	XS #68	319.53	319.40
	XS #67	319.49	319.40
Heart River Right Dyke	XS #63	321.05	320.21
	XS #62	321.13	320.21
	XS #61	321.11	320.21
	XS #60	320.75	320.21
	XS #59	320.65	320.21
	XS #58	321.11	320.21
	XS #57	321.10	320.21
	XS #56	321.03	320.21
	XS #55	321.11	320.21

Table 12 Modelled flood control structure details (continued)

Description	Cross section	Surveyed crest elevation (m)	Effective levee elevation (m)
Heart River Left Dyke	XS #68	321.05	320.74
	XS #67	321.20	320.74
	XS #66	321.81	320.74
	XS #65	321.80	320.74
	XS #64	321.45	320.74
	XS #63	321.27	320.74
	XS #62	321.10	320.74
	XS #61	321.00	320.74
	XS #60	320.74	320.74
	XS #59	321.02	320.74
	XS #58	321.05	320.74
	XS #57	321.01	320.74
	XS #56	320.98	320.74
	XS #55	320.98	320.74

5.2.4 Other Features

Backwater flood inundation along the Smoky River near the mouth was considered, as per the requirements of this study, using simulated water levels from the Peace River near the mouth of the Smoky River. In accordance with the AEP terms of reference for this study, no hydraulic modelling of the Smoky River was required, so no part of the Smoky River was represented explicitly in the hydraulic model.

5.3 Model Calibration

5.3.1 Methodology

Model calibration involved the selection of modelling parameters to simulate observed water levels along the study reach for both high and low flow conditions. The modelling parameters that were calibrated included:

- Manning's roughness coefficient for the channel, islands, and floodplain.
- Roughness adjustment factors varying with discharge.
- Friction slope associated with the downstream normal depth water level boundary condition.
- Ineffective flow areas at each model cross section.
- Expansion and contraction coefficients between cross sections.

Of the above, the primary calibration parameters were the Manning's roughness coefficients for the river channel, which were selected for each cross section by comparing the simulated water surface profile elevations to observed water levels and highwater marks. The challenges or limitations that are typical to the calibration process include:

- The accuracy of the highwater mark elevations.
- Improper identification of highwater marks.
- Uncertainties in estimates of the flood peak discharge.
- Insufficient channel geometry data.

For this study, the major factor affecting the calibration efforts was the uncertainty in discharge estimates associated with the magnitude and timing of flood peaks on the Peace and Smoky rivers for the calibration event.

As a first pass in the model calibration process, roughness within the model domain was defined in ArcGIS based on the land cover as shown in the aerial imagery. The land cover types considered in defining roughness regions are defined in **Table 13**. Further refinement of lateral roughness variations to represent each landcover type was completed on a section by section basis within the HEC-RAS geometry editor, using the DTM and survey information as a guide.

Table 13 Description of land cover types within the study reach

Land cover type	Description
River channel	Includes the wetted channel area and low lying bars with light vegetation that would be easily eroded away by high flow velocity during large flow events
Light vegetation	Agricultural crops or pastureland within the overbank with grasses with a general height of one metre or less
Dense vegetation	Forest cover either in the overbank or on islands with medium/ large size trees with height greater than the depth during the design event
Urban	Development within the wetted width of the design flood, possibly behind a flood control dyke, with buildings taller than the maximum expected flow depth with transportation corridors comprised of either asphalt or gravel between the buildings.

Calibration of Manning's roughness coefficients was done from the most downstream end of the model to the upstream end. While it may be possible to precisely match the simulated water surface profile elevations to the observed values at each location, this generally requires section to section adjustments in channel roughness values that are implausible and not physically-representative of the channel morphology. Instead, channel roughness coefficients were varied on a reach basis, with constant overbank roughness values selected for each land cover type (see Section 5.4.1). Changes in the

Manning's roughness coefficient typically coincide with variations in flow or sediment regime, often indicated by changes in channel planform that can be identified from aerial imagery.

5.3.2 Low Flow Calibration

The bathymetric survey by NHC in October 2015 was completed during low flow conditions. Corresponding measured water levels and WSC gauged discharges were available to calibrate the HEC-RAS model. **Table 14** summarizes the model cross sections surveyed on each day and associated discharges for the Peace River and Smoky River used in the low flow model calibration.

Over the five-day period between 19 and 23 October, the discharge downstream of the Smoky River confluence varied between 1,339 and 1,857 m^3/s. Flowrates were generally declining from the first day to the last day of the survey. Discharge on the Smoky River was relatively consistent during the bathymetric survey, with mean daily flows recorded at Watino declining from 161 m^3/s on 19 October to 149 m^3/s on 23 October. Given that Smoky River flows were small relative to those on the Peace River and the time of travel between the gauge and the mouth is less than half a day, it was deemed appropriate to use the mean daily flows recorded at Watino for each corresponding day.

Table 14 Cross section survey sequence and corresponding discharges used in the low flow model calibration

Date	Peace River cross section numbers where water levels were surveyed	Discharge (m^3/s)	
		Peace River below Smoky River	Smoky River at the mouth
19 October	1, 2, 3, 4, 6, 7, 8, 9	1,740 – 1,857	161
20 October	5, 10, 11, 12, 13, 14, 15	1,585 – 1,702	156
21 October	16, 17, 18, 19, 21 ,23, 24, 25, 26, 28	1,653 – 1,719	157
22 October	29, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41	1,400 – 1,527	152
23 October	42, 43, 44, 45,46, 47, 48, 49, 50, 51, 52, 53, 54	1,339 – 1,481	149

Field observations and available hydrometric information indicated that flow in the Heart River was close to zero for the duration of the fall 2015 survey. This is not unusual for conditions late in the open water season. As the HEC-RAS model includes a portion of the Heart River through TPR, it was necessary to include a non-zero flowrate in the computations. However, it was not possible to calibrate channel roughness for the Heart River as part of the low flow calibration procedure.

Two low flow profiles for the Peace River were established in the model for each day of the October 2015 survey: one representing the maximum reported discharge for the day and another representing the minimum reported discharge for the day. Channel roughness and downstream normal depth water level boundary friction slope were varied so that the maximum and minimum flow water level profiles for each day agreed with measured water levels on the same day. During the calibration process, it was determined that a slightly higher roughness downstream of the Highway 2 bridge yielded better results than a single channel roughness applied along the entire study reach. This result is consistent with a slight reduction in channel slope and somewhat greater preponderance of islands downstream of TPR that would be indicative of increased friction losses.

Minimal emphasis was placed on the low flow calibration when determining the calibrated roughness coefficients, since flow conditions at the time of survey were less than one-fifth the 2-year flood discharge estimate. Results of the low flow calibration are provided in **Section 5.3.5**.

5.3.3 High Flow Calibration

Peace River

As previously noted, the June 1990 flood was the largest flood on record in the study area, with an estimated peak discharge at TPR of 18,545 m^3/s. The magnitude of this flood is nearly double the largest measured discharge from which the WSC rating curve was developed, and the uncertainty of the 1990 peak flood estimate on this extrapolated region of the rating curve is difficult to quantify. Also, given that the peak on the Smoky River at Watino was not measured due to a gauge malfunction during the flood, it was not possible to corroborate the recorded peak at TPR by comparing peak flood discharge estimates at Watino and Dunvegan directly. Other high flow events were considered for calibrating the model; however, observed highwater marks for other events were limited to only one or a few locations along the study reach.

High flow calibration for the June 1990 flood event proceeded as follows:

- The recorded peak discharge at Dunvegan was applied to the modelled reach from the upstream boundary to the Smoky River confluence.
- The recorded peak discharge at TPR was applied to the modelled reach from the Heart River to the downstream study area boundary.
- The estimated peak discharge for the Heart River near the mouth was applied to the modelled Heart River reach.
- The Peace River reach between the Smoky confluence and the Heart River confluence was assigned a discharge equal to the recorded peak at TPR minus the discharge assigned to the Heart River.

Additional consideration was given to coincidence of flood peaks on the Smoky River and Peace River in developing the discharge boundary conditions. As shown in **Table 3**, the recorded peak at TPR occurred at 22:00 on 13 June, while the peak at Dunvegan occurred at 20:00 on 13 June. The time of travel from Dunvegan to TPR based on dynamic flood routing is approximately 10 hours, so highwater marks above the Smoky River confluence are not likely associated directly with peak water levels below the Smoky River. Therefore, two flood profiles were developed for the June 1990 event:

1) For peak flood levels below Smoky River, the peak discharge at TPR (occurring at 22:00 on 13 June) was simulated with a corresponding estimated Peace River discharge of 7,730 m^3/s above Smoky River coincident with this earlier peak. Note that the peak originating from above the Smoky River arrived at TPR approximately 10 hours after it was observed at Dunvegan or approximately 06:00 on 14 June.
2) For peak flood levels above Smoky River, the peak discharge at Dunvegan was simulated with a corresponding estimated Peace River discharge of 18,250 m^3/s coincident with the later peak originating from above the Smoky River at 06:00 on 14 June.

The difference in computed water level between these two flood profiles was 0.1 m or less at cross sections above the Smoky River confluence. The calibrated model was also validated against available highwater observations for 1972, 2001, 2011, and 2012, using the peak flow data provided in **Table 3**.

Heart River

Calibration of the Heart River reach was constrained by limited highwater mark observations along the study reach during open water flood conditions, with the only information available representing backwater-dominated conditions from the Peace River within TPR near the mouth of the river. When the Peace River is in flood condition, water levels along the Heart River study reach are not sensitive to channel roughness.

Additional highwater observations obtained with the assistance of TPR staff during the month of June 2016, however, did provide data that was useful in selecting appropriate channel roughness values the Heart River reach. On 3 June, TPR staff set out six wooden stakes near the edge of water during low flow, at selected locations. The discharge on that day was estimated from provisional gauge records to be 3 m^3/s on the Heart River near the mouth and 2,290 m^3/s on the Peace River. On 20 June, following a highwater event on 18 and 19 June, water levels at two of the stakes were recorded by measurement from the top of the stake. At that time, discharge was estimated from gauge records to be 20.5 m^3/s on the Heart River and 4,780 m^3/s on the Peace River. During NHC's September 2016 survey, the top of stake elevations were surveyed along with additional highwater marks corresponding to the 18 and 19 June event.

5.3.4 Gauge Data and Rating Curves

XS #22, surveyed in September 2016, is at the location of the WSC gauge at Peace River (07HA001). The HEC-RAS model was used to generate a simulated rating curve for discharges from 500 m^3/s to 30,000 m^3/s. The gauge rating curve was used to refine the model calibration and determine a series of Manning's roughness factors that varied with discharge (see Section 5.4.1). The simulated rating curve from the calibrated model compared to the WSC gauge rating curve is shown in **Figure 8**.

WSC also operates a water level gauging station (07FD901) on the Peace River above the Smoky River confluence within the HEC-RAS model domain at XS #42. At this location, water levels can be heavily influenced by backwater effects at times when the Smoky River discharge is high, meaning there is no unique discharge rating curve associated with this gauge that can be used for comparison with model simulation results. Peace River at Dunvegan Bridge (07FD003) is beyond the upstream study area and model boundary and therefore cannot be used to assess the model calibration.

5.3.5 Calibration Results

Peace River

The results of the model calibration consist of a comparison between observed highwater marks and simulated water surface profiles for both high and low flow conditions. **Figure 9** shows the water surface profile for the June 1990 high flow calibration event. A tabular summary of the high flow calibration is provided in **Table 15**. Simulated water levels were on average 0.01 m below observed highwater marks for this event. One suspect highwater mark observation at the Highway 986 Bridge (Daishowa Bridge, river station 4890.1 m) was excluded, since it was 1.21 m above the simulated water surface and 0.4 to 1.3 m above adjacent observed highwater marks upstream and downstream of this location, suggesting an elevation reference datum issue.

The low flow calibration profiles are shown in **Figure 10**. A tabular summary of the low flow calibration is provided in **Table 16**. The simulated water levels were on average 0.02 m above observed water levels over the duration of the survey.

As described in Section 5.1.2, a specified downstream water level boundary condition was required for the Heart River in each simulation. **Table 17** provides a summary of the values used for the calibrated water surface profiles presented in this section.

Table 15 Calibration results for the June 1990 flood

Location	River Station (m)	Date	Discharge (m^3/s)	Observed Highwater Mark (m)	Simulated Water Level (m)	Simulated Minus Observed (m)
Shaftsbury Ferry	48294.3	14-Jun-90	7,730	323.93	323.99	0.06
Simpson's Residence	42701.4	14-Jun-90	7,730	323.17	323.18	0.01
Mackenzie Cairn	39960.8	14-Jun-90	7,730	322.76	322.72	-0.04
Correctional Centre	37240.4	14-Jun-90	7,730	322.40	322.40	0.00
Purcell's	35279.4	14-Jun-90	7,730	322.15	322.23	0.08
Old Highway	32784.8	14-Jun-90	7,730	322.00	322.07	0.07
Macleod Cairn	31893.5	14-Jun-90	7,730	322.06	322.04	-0.02
Power Pole	31699.4	14-Jun-90	7,730	322.01	322.03	0.02
Gravel Pit	29357.8	14-Jun-90	7,730	321.60	321.55	-0.05
Sawchuck's	28102.7	14-Jun-90	7,730	320.72	321.30	0.58
West Peace Boat Launch	23487.2	13-Jun-90	18,472	319.71	319.58	-0.13
Heart River at Musuem	23448.4	13-Jun-90	18,472	319.66	319.54	-0.12
West Peace North End	23278.8	13-Jun-90	18,545	319.40	319.39	-0.01
W.H.Wood's	22648.5	13-Jun-90	18,545	319.11	319.15	0.04
Rail Bridge	22095.6	13-Jun-90	18,545	318.83	318.75	-0.08
Hwy 2 Bridge	22001.5	13-Jun-90	18,545	318.61	318.67	0.06
WSC Gauge	21323.8	13-Jun-90	18,545	318.69	318.74	0.05
Bewley Island 2	20896.7	13-Jun-90	18,545	318.61	318.69	0.08
Czuy's House	19600.8	13-Jun-90	18,545	318.34	318.14	-0.20
Dick's Diving	16958.3	13-Jun-90	18,545	317.93	317.66	-0.27
Six Mile Farm	13921.8	13-Jun-90	18,545	316.76	316.82	0.06
Birch Island	6265.6	13-Jun-90	18,545	315.21	314.90	-0.31
Daishowa Bridge	4890.1	13-Jun-90	18,545	315.60	314.39	-1.21
Daishowa Intake	4476.8	13-Jun-90	18,545	314.30	314.19	-0.11
Shell Intake	1565.1	13-Jun-90	18,545	313.53	313.47	-0.06

Table 16 Calibration results for October 2015 low flow conditions

Location	River Station (m)	Date	Discharge (m^3/s)	Observed Water Level (m)	Simulated Water Level (m)	Simulated Minus Observed (m)
XS #54	54139.1	23-Oct-15	1332	321.37	321.26	-0.11
XS #53	52544.4	23-Oct-15	1332	320.66	320.66	0.00
XS #52	50979.5	23-Oct-15	1332	319.89	320.03	0.14
XS #51	49803.2	23-Oct-15	1332	319.60	319.61	0.01
XS #50	48297.0	23-Oct-15	1332	319.45	319.37	-0.08
XS #49	47054.7	23-Oct-15	1332	319.25	319.22	-0.03
XS #48	45563.6	23-Oct-15	1332	318.81	318.84	0.03
XS #47	44051.3	23-Oct-15	1332	318.13	318.18	0.05
XS #46	42705.2	23-Oct-15	1332	317.50	317.54	0.04
XS #45	41405.6	23-Oct-15	1332	317.00	317.05	0.05
XS #44	39966.2	23-Oct-15	1332	316.51	316.65	0.14
XS #43	38663.5	23-Oct-15	1332	316.42	316.36	-0.06
XS #42	37246.3	23-Oct-15	1332	316.14	316.00	-0.14
XS #41	35284.7	22-Oct-15	1375	315.39	315.48	0.09
XS #40	33566.0	22-Oct-15	1375	315.11	315.11	0.00
XS #39	31899.6	22-Oct-15	1375	314.79	314.67	-0.12
XS #38	30757.8	22-Oct-15	1375	314.32	314.21	-0.11
XS #37	28861.6	22-Oct-15	1527	313.97	313.78	-0.19
XS #36	28108.3	22-Oct-15	1527	313.89	313.58	-0.31
XS #35	27059.9	22-Oct-15	1527	313.06	313.12	0.06
XS #34	26167.3	22-Oct-15	1527	312.67	312.70	0.03
XS #33	25065.3	22-Oct-15	1527	312.18	312.26	0.08
XS #32	24146.4	22-Oct-15	1527	311.88	312.04	0.16
XS #31	23492.6	N/A	N/A	N/A	311.96	N/A
XS #30	23295.0	22-Oct-15	1527	311.78	311.92	0.14
XS #29	22393.0	22-Oct-15	1527	311.74	311.86	0.12
XS #28	22118.1	21-Oct-15	1653	311.93	311.94	0.01
XS #27	22100.7	N/A	N/A	N/A	311.73	N/A

Table 16 Calibration results for October 2015 low flow conditions (continued)

Location	River Station (m)	Date	Discharge (m^3/s)	Observed Water Level (m)	Simulated Water Level (m)	Simulated Minus Observed (m)
XS #26	22063.8	21-Oct-15	1653	311.67	311.73	0.06
XS #25	22027.4	21-Oct-15	1653	311.84	311.73	-0.11
XS #24	22007.4	21-Oct-15	1653	311.83	311.72	-0.11
XS #23	21736.0	21-Oct-15	1653	311.80	311.70	-0.10
XS #22	21329.3	N/A	N/A	N/A	311.62	N/A
XS #21	20902.1	21-Oct-15	1653	311.40	311.38	-0.02
XS #20	20583.9	N/A	N/A	N/A	311.20	N/A
XS #19	19733.3	21-Oct-15	1653	310.94	310.92	-0.02
XS #18	18523.1	21-Oct-15	1653	310.19	310.45	0.26
XS #17	16963.1	21-Oct-15	1653	309.41	309.52	0.11
XS #16	15681.7	21-Oct-15	1653	308.59	308.76	0.17
XS #15	14591.1	20-Oct-15	1585	308.23	308.18	-0.05
XS #14	13053.2	20-Oct-15	1585	307.56	307.73	0.17
XS #13	11809.6	20-Oct-15	1585	307.25	307.42	0.17
XS #12	10385.1	20-Oct-15	1585	306.86	307.07	0.21
XS #11	9024.8	20-Oct-15	1585	306.65	306.76	0.11
XS #10	7564.1	20-Oct-15	1585	305.98	306.21	0.23
XS #09	6270.6	19-Oct-15	1857	305.70	305.94	0.24
XS #08	5365.3	19-Oct-15	1857	305.37	305.58	0.21
XS #07	4915.2	19-Oct-15	1857	305.36	305.53	0.17
XS #06	4895.6	19-Oct-15	1857	305.34	305.35	0.01
XS #05	4480.9	20-Oct-15	1585	305.01	304.92	-0.09
XS #04	3709.0	19-Oct-15	1857	304.95	305.00	0.05
XS #03	2382.4	19-Oct-15	1857	304.30	304.35	0.05
XS #02	1302.7	19-Oct-15	1857	304.12	303.78	-0.34
XS #01	0.0	19-Oct-15	1857	303.52	303.31	-0.21

Table 17 Peace River calibrated water levels applied to Heart River downstream boundary

Calibration Profile	Peace River Discharge (m^3/s)	XS #30 Simulated Water Level (m)	XS #31 Simulated Water Level (m)	XS #55 Boundary Water Level (m)
13-14 June 1990 (Peace, high-flow)	18,545	319.40	319.58	319.49
19 October 2015 (Peace, low-flow)	1857	312.19	312.24	312.22
20 October 2015 (Peace, low-flow)	1585	311.97	312.01	311.99
21 October 2015 (Peace, low-flow)	1653	312.03	312.07	312.05
22 October 2015 (Peace, low-flow)	1527	311.92	311.96	311.94
23 October 2015 (Peace, low-flow)	1481	311.89	311.93	311.91
3 June 2016 (Heart River)	2290	312.52	312.58	312.55
20 June 2016 (Heart River)	4780	313.96	314.07	314.02

Note: Boundary water level at XS #55 on the Heart River was taken as the average of XS #30 and #31 on the Peace River.

Heart River

The best available information for calibration of the Heart River channel roughness at times when flood levels on the Peace River were not dominating the backwater profile on the Heart River were derived from observations made on 3 June and 20 June 2016, as described earlier in **Section 5.3.3**. Of the six stakes set on 3 June, only three were found remaining in-place during NHC's September 2016 follow-up survey to confirm highwater mark elevations. Of those three stakes, only two were observed extending above the water surface on 20 June, with the third believed to be fully-submerged at the time. **Table 18** summarizes the Heart River calibration results. The corresponding water surface profiles are shown in **Figure 11**.

Table 18 Calibration results for Heart River based on June 2016 observations

Location	River Station (m)	Heart River Discharge (m^3/s)	Peace River Discharge (m^3/s)	Observed Water Level (m)	Simulated Water Level (m)	Simulated Minus Observed (m)
3 June 2016						
Stake #4	473.4	3	2,290	314.38	314.16	-0.22
Stake #3	375.0			313.93	313.88	-0.05
Stake #2	202.0			313.09	313.25	0.16
20 June 2016						
Stake #4	473.4	20	4,780	314.84	314.99	0.15
Stake #3	375.0			314.61	314.55	-0.06

It should be noted that the observed water level elevations in the table above were surveyed indirectly as follows:

- Documentation from 3 June indicated that the stakes were set near the edge of water on the day. The top and bottom of stake elevations were surveyed by NHC on 13 and 14 September 2016. The water level was assumed to be equal to the bottom of stake elevation, but this should be considered approximate.
- Documentation from 20 June indicated measured distances from the top of stake to the water surface in inches. Those measurements were converted to metres and related to the surveyed top of stake elevations from 13 and 14 September 2016.

5.4 Model Parameters and Options

The following sections describe the key model parameters and options adopted in the calibrated HEC-RAS model. These include Manning's roughness coefficients for the channel and overbank areas, contraction and expansion loss coefficients, ineffective areas, and geometric configuration around flow splits, islands, and diversions.

5.4.1 Manning's Roughness Values

Computations in HEC-RAS are based on quantifying the friction loss between cross sections on the basis of Manning's roughness coefficient, a parameter that accounts for river bottom material size and shape, floodplain condition (including vegetation and developed area), and the general river planform variation. The effective Manning's roughness for a channel decreases with increasing discharge, and one particular set of values should be considered valid only for a range of discharges of similar magnitude to the calibration event. A description of the channel and floodplain roughness values adopted in the model is provided below.

Channel Roughness

Table 19 summarizes the calibrated channel roughness at each model cross section based on the high flow calibration for the June 1990 flood. During development of the model and initial calibration efforts, it was determined that a single channel roughness value along the entire study reach would not produce acceptable agreement between simulated water levels and observed highwater marks. The data indicated a higher channel roughness along the downstream reach as compared to the upstream reach, with the transition occurring in the area between the Highway 2 bridge crossing the Peace River and the upstream end of Bewley Island. The roughness change can be attributed to a mild increase in sinuosity and bed slope in the downstream reach. Channel roughness for the Heart River was found to be higher than that of the Peace River, which is consistent with the relative size of the channel and geomorphic characteristics of this tributary.

Table 19 Adopted Manning's roughness values for the channel based on high flow calibration

Reach Description	Cross Sections	Channel Roughness
Peace River above WSC gauge 07HA001 at TPR	XS #23 to XS #54	0.022
Peace River from WSC gauge 07HA001 at TPR to the downstream study area limit	XS #01 to XS #22	0.024
Heart River from the upstream study area limit to the mouth	XS #55 to XS #81	0.044

The above base calibration for channel roughness was enhanced by varying Manning's roughness with discharge on the Peace River. This relationship was determined by trial and error simulation and comparison to the published WSC rating curve (07HA001, see **Figure 8**) at TPR for a range of flows from 500 m^3/s up to 30,000 m^3/s. The relationship derived between channel roughness and discharge is shown in **Figure 12** and summarized in **Table 20**. Over the range of flows examined, effective channel roughness ranged from 0.040 down to 0.021 in the reach above WSC gauge 07HA001 and likewise ranged from 0.043 down to 0.023 in the reach from the gauge to the downstream study limit.

Table 20 Calibrated variation of Manning's roughness with discharge – Peace River reach

Peace River Discharge (m^3/s)	Channel Roughness	
	XS #01 to XS #22	XS #23 to XS #54
500	0.043	0.040
1000	0.036	0.033
1500	0.030	0.028
2000	0.029	0.026
2500	0.028	0.026
3500	0.027	0.025
4000	0.026	0.024
5000	0.026	0.024
6500	0.025	0.023
8000	0.024	0.022
9500	0.024	0.022
11,000	0.024	0.022
12,500	0.024	0.022
14,000	0.024	0.022
15,500	0.024	0.022
17,000	0.024	0.022
18,500	0.024	0.022
20,000	0.024	0.022

Table 20 Calibrated variation of Manning's roughness with discharge – Peace River reach (continued)

Peace River Discharge (m^3/s)	Channel Roughness	
	XS #01 to XS #22	XS #23 to XS #54
21,500	0.024	0.022
23,000	0.023	0.022
24,500	0.023	0.021
26,000	0.023	0.021
27,500	0.023	0.021
29,000	0.023	0.021
30,000	0.023	0.021

This process could not be applied to the Heart River using the available data, and the relationship derived for the Peace River was not representative of this tributary. Also, the reach of interest along the Heart River is dominated by backwater conditions from the Peace River, causing simulated water levels to be relatively insensitive to roughness variations under flood conditions.

Overbank Roughness

Overbank roughness values were selected based on landcover composition, professional judgement, and guidance in the literature (e.g. Chow, 1959). **Table 21** shows the adopted roughness values for the landcover types identified within the study area.

Table 21 Adopted Manning's roughness values for overbank areas

Landcover Description	Channel Roughness
Lightly vegetated areas	0.060
Densely vegetated areas	0.080
Developed urban areas	0.080

The majority of the overbank areas were classified as either densely vegetated or developed urban areas and assigned a roughness value of 0.080. Other areas dominated by sparse vegetation or grasses, either on islands and bars or in the floodplain, were assigned a lower roughness of 0.060.

5.4.2 Contraction and Expansion Loss Coefficients

To account for the effect of flow contraction or expansion on the energy balance between successive cross sections, HEC-RAS multiplies the absolute difference in velocity head by a coefficient. Coefficients range from 0.10 for gradual transitions to 0.80 (Brunner, 2016).

Contraction and expansion loss coefficients at cross sections immediately adjacent to bridges were set to 0.3 and 0.5, respectively, to represent the mild flow area obstruction associated with the bridge piers and abutments. The default values of 0.1 and 0.3 for contraction and expansion loss coefficients were used at all other cross sections.

5.4.3 Ineffective Flow Areas and Blocked Obstructions

About Ineffective Flow Areas

Ineffective flow areas were specified at cross sections in the HEC-RAS model, based on a detailed review of the local terrain and floodplain features both at and between cross sections. Ineffective flow areas can be specified within portions of cross sections where water is expected to pond, but where the velocity of that water, in the downstream direction, is also expected to be close to or equal to zero (Brunner, 2016). The downstream direction is taken relative to the cross section lines defined in the model, so the orientation of cross sections was considered when specifying ineffective flow areas.

Ineffective flow areas in the model may be specified as either permanent or non-permanent. Permanent ineffective flow areas apply regardless of the water surface elevation, whereas temporary ineffective flow areas become effective above a defined elevation. The configuration of permanent and non-permanent ineffective flow areas were specified, depending on site-specific circumstances and engineering judgement.

General Criteria Used to Define Ineffective Areas

The general criteria applied for determining ineffective flow areas were:

- Non-permanent ineffective flow areas were used to “fill” local depressions on islands or floodplains that are obstructed by higher ground upstream or downstream. These areas were assumed to become engaged in the active flow area once the water level exceeded the elevation of the adjacent ground. For example, XS #19 provides a temporary ineffective flow area on the right side of Bewley Island, since water cannot flow in this area until the water level exceeds the elevation of the surrounding terrain.
- Permanent ineffective flow areas were defined where flow patterns were likely to be influenced by nearby bridge abutments and roadway embankments crossing the floodplain. These types of obstructions tend to direct flows towards the bridge opening. Several site-specific factors were taken into account when configuring ineffective flow areas at bridges in the study area, including: distance from the cross section to the bridge, terrain features, bridge geometry, and skew of the bridge opening relative to the river. XS #5, #6, #7, #8, #23, and #29 provide ineffective flow areas related to nearby bridges. XS #24 through #28 did not require ineffective flow areas to represent the abutments or road embankments because these features were captured in the cross section elevation data directly. The bridges crossing the Heart River do not obstruct the overbank floodplain; however, ineffective areas along this reach were required to represent flood control dykes (see ***Ineffective Areas Behind Flood Control Structures***, below).

- Permanent ineffective flow areas on the left overbank were specified to the maximum cross section elevation on cross sections #55 through #62 near the mouth of the Heart River. This region was deemed ineffective since flow in these areas would be dominated by the Peace River floodplain flow; there would be no effective contribution from the Heart River in these areas. The left overbank portions of these cross sections were oriented in the upstream direction to facilitate floodplain mapping as noted in Section 5.1.2 and to meet the requirements of AEP's terms of reference for this study.

Ineffective Areas Behind Flood Control Structures

Permanent ineffective flow areas were also defined behind flood control structures such that they worked in combination with specified levees to simulate a plausible degree of floodplain conveyance in the overbank areas across the full range of flood discharges of interest. The top elevation of these ineffective areas was set at or below the existing flood control dyke crest elevation, taking into consideration upstream and downstream flow-limiting elevations through connected floodplain areas. For scenarios that overtop the flood control structures in this study, the above configuration was chosen to ensure that flood levels were reasonable but not under-represented.

The overbank discharge computed by the model was a primary factor in establishing the configuration of representative ineffective flow areas behind flood control structures. A comparison was done with and without permanent ineffective areas to assess sensitivity of the model to these configurations. For flood scenarios that overtopped the flood control structures, significant variation in overbank discharge was noted between cross sections where large overbank areas were activated. For example, downstream of the Highway 2 bridge (from XS #19 to 24) the overbank discharge computed for the 500-year flood was four to five times larger and the magnitude of the overbank discharge increased by a factor of four between XS #20 and #19 when using non-permanent ineffective areas. Although the overbank discharge was relatively small in comparison to the main channel flow for both configurations, continuity (i.e. the variation in overbank discharge between successive cross sections) was more technically-defensible when permanent ineffective areas were used. This was the primary rationale for specifying such areas as permanently ineffective for modelling purposes. The comparison also showed that the effect on simulated water levels was approximately 0.05 m, within the vicinity of TPR only, for flood scenarios that overtopped the flood control structures; there was no impact on the results for smaller floods. This suggests that simulated water levels were not sensitive to the modelling approach.

Although areas behind and below the crest of the structures may be specified as permanently ineffective for hydraulic modelling purposes, it must be noted that relatively high flow velocities could occur in those areas, if the structures are breached or overtopped.

Blocked Obstructions

Blocked obstructions in the floodplain, such as buildings, walls, storage tanks, or elevated foundations were not specified in the HEC-RAS model. Obstructions associated with bridge piers and structural members were modelled using the standard bridge editor specifications in HEC-RAS.

5.4.4 Flow Splits, Islands and Diversions

The study reaches were adequately represented without flow splits around islands. Where a cross section intersected an island, the HEC-RAS model assumed equal water level on both sides of an island based on the composite channel conveyance properties and computed energy losses. As flood magnitude increases or where the effective flow path distance between cross sections on either side of an island are similar, this approximation is generally accurate.

Diversions may include evulsion channels or flow paths that reduce the total discharge carried by the main channel along a portion of the study reach. There were no such diversions encountered within the study area, and all flood flows were confined to the cross sections modelled along the Peace River valley.

5.5 Open Water Flood Frequency Profiles

The calibrated hydraulic model was used to generate flood frequency profiles for the thirteen naturalized open water floods of varying magnitude listed in **Table 4**. The computed flood frequency water levels at each surveyed cross section on the Peace River are provided in **Table 22**. As described in Section 5.1.2, the average of the computed water levels for XS #30 and #31 were used as the downstream boundary water level for the Heart River; these boundary condition values are also provided in **Table 22** for reference on the row marked *Heart River*. Computed flood frequency water levels for the Heart River are provided in **Table 23**. These results are plotted graphically in **Figure 13** for the Peace River and **Figure 14** for the Heart River. The values for XS #55 represent the specified boundary water levels noted above.

These results indicate that the deck elevations for bridges crossing the Peace River are well above the 1000-year flood level, with the bottom chord for the left and right portions of the CPR bridge being just above the 500-year open water flood level. On the Heart River, the low chord of the 101 Street bridge is situated the lowest, just above the 10-year (Peace River backwater) flood level.

The crest of the flood control dykes on both the east and west side of the Peace River through town generally sit about 0.95 m above the 100-year open water flood level and would be expected to be overtopped at multiple locations for the 200-year flood event.

Table 22 Computed flood frequency water levels – Peace River

Cross Section	Flood Return Period						
	2-year	5-year	10-year	20-year	35-year	50-year	75-year
	Water Surface Elevation (m)						
XS #54	325.29	326.14	326.69	327.14	327.54	327.78	328.10
XS #53	324.60	325.44	326.02	326.49	326.90	327.15	327.48
XS #52	324.14	324.98	325.54	326.01	326.41	326.66	326.98
XS #51	323.84	324.68	325.23	325.70	326.10	326.35	326.66
XS #50	323.42	324.20	324.71	325.16	325.55	325.79	326.09
XS #49	323.13	323.91	324.42	324.88	325.28	325.53	325.84
XS #48	322.68	323.50	324.05	324.54	324.97	325.23	325.57
XS #47	322.29	323.13	323.69	324.20	324.65	324.92	325.26
XS #46	322.05	322.90	323.47	324.00	324.44	324.73	325.07
XS #45	321.51	322.40	323.02	323.59	324.07	324.37	324.74
XS #44	321.12	321.94	322.51	323.07	323.54	323.83	324.19
XS #43	320.67	321.51	322.10	322.69	323.19	323.50	323.87
XS #42	320.25	321.09	321.68	322.30	322.81	323.14	323.51
XS #41	319.69	320.52	321.14	321.82	322.37	322.71	323.11
XS #40	319.25	320.07	320.68	321.40	321.96	322.32	322.72
XS #39	318.98	319.80	320.43	321.18	321.77	322.14	322.55
XS #38	318.55	319.44	320.11	320.94	321.56	321.96	322.39
XS #37	317.57	318.56	319.30	320.28	320.99	321.42	321.88
XS #36	317.49	318.50	319.24	320.21	320.90	321.33	321.78
XS #35	317.10	318.11	318.84	319.85	320.58	321.02	321.48
XS #34	316.88	317.94	318.72	319.79	320.52	320.97	321.44
XS #33	316.54	317.60	318.35	319.34	320.08	320.54	321.03
XS #32	316.23	317.25	317.96	318.77	319.44	319.86	320.33
XS #31	316.03	317.03	317.72	318.52	319.17	319.60	320.06
Heart River	*315.96*	*316.95*	*317.64*	*318.44*	*319.08*	*319.51*	*319.97*
XS #30	315.88	316.86	317.55	318.35	318.99	319.42	319.87
XS #29	315.65	316.60	317.26	318.04	318.66	319.07	319.51
XS #28	315.59	316.54	317.21	317.99	318.62	319.03	319.47
XS #27	315.36	316.30	316.97	317.74	318.36	318.77	319.20
XS #26	315.35	316.29	316.96	317.73	318.35	318.76	319.20
XS #25	315.35	316.29	316.95	317.72	318.35	318.75	319.19
XS #24	315.32	316.25	316.90	317.66	318.28	318.68	319.12

Table 22 Computed flood frequency water levels – Peace River (continued)

Cross Section	Flood Return Period					
	100-year	200-year	350-year	500-year	750-year	1000-year
	Water Surface Elevation (m)					
XS #54	328.30	328.83	329.24	329.53	329.85	330.09
XS #53	327.69	328.23	328.65	328.95	329.29	329.54
XS #52	327.18	327.72	328.14	328.44	328.78	329.04
XS #51	326.87	327.41	327.83	328.14	328.48	328.74
XS #50	326.29	326.83	327.25	327.55	327.90	328.16
XS #49	326.04	326.61	327.04	327.36	327.72	328.00
XS #48	325.78	326.40	326.87	327.21	327.60	327.91
XS #47	325.49	326.13	326.61	326.96	327.36	327.66
XS #46	325.31	325.95	326.45	326.80	327.21	327.52
XS #45	324.99	325.67	326.19	326.56	326.99	327.31
XS #44	324.44	325.13	325.66	326.05	326.50	326.83
XS #43	324.12	324.86	325.42	325.82	326.29	326.64
XS #42	323.78	324.54	325.12	325.53	326.01	326.37
XS #41	323.38	324.19	324.80	325.24	325.74	326.12
XS #40	323.00	323.84	324.45	324.90	325.41	325.80
XS #39	322.84	323.71	324.34	324.80	325.33	325.72
XS #38	322.69	323.59	324.25	324.72	325.27	325.67
XS #37	322.20	323.15	323.83	324.31	324.86	325.26
XS #36	322.10	323.04	323.70	324.17	324.71	325.11
XS #35	321.81	322.78	323.45	323.92	324.47	324.87
XS #34	321.77	322.75	323.43	323.91	324.45	324.86
XS #33	321.38	322.40	323.08	323.57	324.13	324.54
XS #32	320.66	321.65	322.29	322.74	323.27	323.66
XS #31	320.38	321.37	321.99	322.45	322.97	323.35
Heart River	*320.29*	*321.29*	*321.91*	*322.36*	*322.89*	*323.27*
XS #30	320.20	321.20	321.82	322.27	322.80	323.19
XS #29	319.82	320.78	321.37	321.79	322.28	322.64
XS #28	319.79	320.76	321.35	321.77	322.26	322.63
XS #27	319.52	320.48	321.06	321.48	321.96	322.32
XS #26	319.51	320.48	321.06	321.48	321.96	322.32
XS #25	319.51	320.48	321.06	321.48	321.96	322.32
XS #24	319.43	320.38	320.95	321.36	321.83	322.18

Table 22 Computed flood frequency water levels – Peace River (continued)

Cross Section	Flood Return Period						
	2-year	5-year	10-year	20-year	35-year	50-year	75-year
	Water Surface Elevation (m)						
XS #23	315.29	316.23	316.89	317.67	318.30	318.70	319.15
XS #22	315.25	316.21	316.90	317.69	318.34	318.76	319.22
XS #21	315.08	316.09	316.79	317.61	318.27	318.71	319.18
XS #20	314.90	315.90	316.61	317.45	318.14	318.58	319.07
XS #19	314.60	315.61	316.32	317.12	317.76	318.17	318.62
XS #18	314.29	315.40	316.15	316.97	317.63	318.04	318.50
XS #17	313.79	314.96	315.74	316.59	317.25	317.68	318.14
XS #16	313.46	314.65	315.44	316.29	316.96	317.39	317.85
XS #15	313.13	314.31	315.09	315.94	316.61	317.04	317.51
XS #14	312.62	313.82	314.62	315.46	316.13	316.55	317.01
XS #13	312.42	313.62	314.41	315.25	315.92	316.34	316.80
XS #12	311.99	313.19	313.97	314.80	315.46	315.88	316.33
XS #11	311.67	312.88	313.67	314.50	315.17	315.58	316.04
XS #10	311.42	312.67	313.49	314.34	315.02	315.45	315.92
XS #9	311.05	312.26	313.05	313.87	314.51	314.92	315.35
XS #8	310.81	312.04	312.85	313.68	314.33	314.74	315.19
XS #7	310.76	311.99	312.78	313.60	314.25	314.66	315.10
XS #6	310.53	311.75	312.54	313.35	314.00	314.40	314.84
XS #5	310.39	311.60	312.37	313.17	313.80	314.20	314.63
XS #4	310.17	311.36	312.12	312.91	313.53	313.92	314.34
XS #3	309.86	311.06	311.83	312.63	313.26	313.66	314.08
XS #2	309.54	310.77	311.56	312.38	313.02	313.43	313.87
XS #1	309.10	310.31	311.09	311.90	312.54	312.95	313.38

Table 22 Computed flood frequency water levels – Peace River (continued)

Cross Section	Flood Return Period					
	100-year	200-year	350-year	500-year	750-year	1000-year
	Water Surface Elevation (m)					
XS #23	319.46	320.43	321.02	321.44	321.93	322.29
XS #22	319.54	320.54	321.15	321.59	322.09	322.47
XS #21	319.51	320.52	321.14	321.59	322.11	322.49
XS #20	319.41	320.45	321.08	321.54	322.06	322.45
XS #19	318.95	319.93	320.60	321.10	321.66	322.08
XS #18	318.84	319.72	320.41	320.91	321.48	321.90
XS #17	318.47	319.36	320.05	320.55	321.12	321.53
XS #16	318.18	319.07	319.76	320.25	320.82	321.24
XS #15	317.85	318.73	319.43	319.92	320.49	320.91
XS #14	317.35	318.25	318.93	319.43	320.00	320.41
XS #13	317.14	318.02	318.71	319.20	319.77	320.18
XS #12	316.66	317.53	318.21	318.69	319.25	319.65
XS #11	316.37	317.25	317.92	318.41	318.97	319.37
XS #10	316.26	317.16	317.87	318.37	318.95	319.37
XS #9	315.67	316.53	317.19	317.67	318.21	318.61
XS #8	315.51	316.37	317.04	317.53	318.08	318.48
XS #7	315.42	316.27	316.92	317.39	317.93	318.32
XS #6	315.16	316.01	316.66	317.13	317.66	318.05
XS #5	314.94	315.77	316.40	316.86	317.38	317.76
XS #4	314.64	315.46	316.08	316.53	317.04	317.42
XS #3	314.39	315.22	315.85	316.31	316.84	317.22
XS #2	314.18	315.03	315.69	316.16	316.70	317.09
XS #1	313.69	314.53	315.18	315.64	316.17	316.56

Table 23 Computed flood frequency water levels – Heart River

Cross Section	Flood Return Period						
	2-year	5-year	10-year	20-year	35-year	50-year	75-year
	Water Surface Elevation (m)						
XS #81	319.33	319.92	320.26	320.48	320.63	320.76	320.97
XS #80	318.86	319.46	319.78	320.01	320.24	320.45	320.73
XS #79	318.52	319.06	319.38	319.74	320.10	320.36	320.68
XS #78	318.14	318.67	319.05	319.53	319.95	320.24	320.56
XS #77	317.70	318.33	318.80	319.36	319.82	320.13	320.49
XS #76	317.42	318.12	318.64	319.25	319.74	320.07	320.44
XS #75	317.19	317.92	318.48	319.13	319.66	320.02	320.41
XS #74	317.10	317.83	318.40	319.06	319.61	319.98	320.38
XS #73	317.02	317.72	318.29	318.96	319.53	319.92	320.34
XS #72	316.73	317.55	318.18	318.89	319.48	319.89	320.32
XS #71	316.54	317.48	318.13	318.86	319.46	319.86	320.29
XS #70	316.45	317.44	318.09	318.83	319.44	319.84	320.28
XS #69	316.30	317.30	317.96	318.71	319.34	319.75	320.21
XS #68	316.25	317.27	317.94	318.70	319.32	319.74	320.20
XS #67	316.21	317.23	317.90	318.67	319.30	319.72	320.18
XS #66	316.19	317.21	317.89	318.66	319.29	319.72	320.18
XS #65	316.06	317.06	317.73	318.52	319.16	319.60	320.06
XS #64	316.05	317.05	317.73	318.52	319.16	319.60	320.06
XS #63	316.03	317.05	317.74	318.53	319.18	319.62	320.09
XS #62	316.02	317.03	317.72	318.52	319.17	319.60	320.07
XS #61	315.99	317.00	317.69	318.50	319.15	319.59	320.06
XS #60	315.99	316.99	317.69	318.49	319.15	319.59	320.06
XS #59	315.98	316.99	317.68	318.48	319.11	319.54	320.00
XS #58	315.97	316.96	317.65	318.45	319.09	319.52	319.98
XS #57	315.96	316.96	317.65	318.44	319.08	319.51	319.97
XS #56	315.96	316.95	317.64	318.44	319.08	319.51	319.97
XS #55	315.96	316.95	317.64	318.44	319.08	319.51	319.97

Table 23 Computed flood frequency water levels – Heart River (continued)

Cross Section	Flood Return Period					
	100-year	200-year	350-year	500-year	750-year	1000-year
	Water Surface Elevation (m)					
XS #81	321.14	321.79	322.28	322.65	323.12	323.47
XS #80	320.95	321.70	322.22	322.61	323.08	323.43
XS #79	320.91	321.70	322.22	322.61	323.08	323.43
XS #78	320.82	321.65	322.19	322.58	323.06	323.42
XS #77	320.77	321.62	322.17	322.57	323.05	323.41
XS #76	320.72	321.59	322.14	322.54	323.03	323.39
XS #75	320.70	321.58	322.14	322.54	323.03	323.39
XS #74	320.68	321.57	322.13	322.53	323.03	323.39
XS #73	320.64	321.55	322.11	322.52	323.01	323.37
XS #72	320.62	321.54	322.11	322.51	323.01	323.37
XS #71	320.60	321.52	322.09	322.50	323.00	323.36
XS #70	320.58	321.52	322.09	322.50	323.00	323.36
XS #69	320.53	321.49	322.07	322.49	322.99	323.35
XS #68	320.52	321.49	322.07	322.48	322.98	323.35
XS #67	320.51	321.47	322.06	322.47	322.98	323.34
XS #66	320.50	321.46	322.04	322.46	322.96	323.33
XS #65	320.39	321.35	321.92	322.36	322.88	323.26
XS #64	320.39	321.36	321.93	322.37	322.89	323.27
XS #63	320.41	321.38	321.95	322.39	322.91	323.28
XS #62	320.40	321.37	321.95	322.38	322.90	323.28
XS #61	320.39	321.36	321.94	322.38	322.90	323.28
XS #60	320.39	321.36	321.94	322.38	322.90	323.28
XS #59	320.32	321.31	321.92	322.37	322.90	323.27
XS #58	320.29	321.29	321.91	322.36	322.89	323.27
XS #57	320.29	321.29	321.91	322.36	322.89	323.27
XS #56	320.29	321.29	321.91	322.36	322.89	323.27
XS #55	320.29	321.29	321.91	322.36	322.89	323.27

5.6 Model Sensitivity

The sensitivity of the calibrated open water hydraulic model to adjustments in boundary conditions and Manning's roughness values was evaluated. These parameters affect the computed water surface profiles and, by direct result, predicted flood depths and inundation limits. The sensitivity analysis provides an indication of the plausible range of error in the calibrated model results and identifies the relative importance of each parameter to the overall error. Generally, the adopted flood discharge and channel roughness values are more sensitive parameters than downstream boundary condition and overbank roughness. Detailed results of the sensitivity analysis are provided below. Since the water level at the mouth of the Heart River is determined by water levels on the Peace River (see Section 5.1.2), results are provided for the Heart River for each scenario involving parameter sensitivity on the Peace River.

5.6.1 Boundary Conditions

The hydraulic model requires a downstream water level and an upstream discharge as boundary conditions for each river reach. The adopted downstream boundary condition in the calibrated model was a normal depth, which was given by specifying an estimate of the energy grade slope equal to 0.00025 m/m at the most downstream cross section. At the 100-year flood frequency discharge, this corresponds to a water surface elevation of 313.69 m at the downstream boundary. A plausible range of uncertainty in this elevation is considered to be ±0.5 m, which corresponds to energy grade slopes for normal depth conditions of 0.000216 m/m (downstream water level of 314.19 m) and 0.000292 m/m (downstream water level of 313.19 m). The results are presented in **Table 24** and **Figure 15**.

The deviation from the calibrated profile falls below 0.1 m beyond XS #18 for the low water level case and XS #29 for the high water level case. The average deviation from the calibrated profile is 0.11 and 0.13 m, respectively for the low and high water level cases on the Peace River and 0.05 and 0.08 m for the corresponding cases on the Heart River.

The lower and upper limits of the 95% confidence interval for the 100-year instantaneous peak discharges above and below the Smoky River were also examined in the sensitivity analysis. Since Heart River flood levels are dominated by backwater from the Peace River, discharge was not varied on the Heart River for this analysis; however, sensitivity analysis results are presented for the Heart River based on backwater conditions from the Peace River. The 100-year flood level sensitivity results at the 95% confidence limits are provided in **Table 25** and **Figure 16**.

The deviation from the calibrated profile in this instance on the Peace River ranges from 0.51 to 1.13 m, with an average deviation of 0.65 m below the calibrated profile for the lower limit discharge and 0.95 m above the calibrated profile for the upper limit discharge. On the Heart River, the deviation from the calibrated profile ranges from 0.18 to 1.08 m, with an average deviation of 0.57 m below the calibrated profile for the lower limit discharge and 0.95 m above the calibrated profile for the upper limit discharge.

Table 24 Sensitivity analysis results for downstream boundary condition

Cross Section	100-Year Flood Levels (m) for Varying Downstream Boundary Condition		
	0.5 m Below Adopted S=0.000292 m/m	Adopted Normal Depth S=0.00025 m/m	0.5 m Above Adopted S=0.000216 m/m
Peace River			
XS #54	328.30	328.30	328.30
XS #53	327.68	327.69	327.69
XS #52	327.17	327.18	327.19
XS #51	326.86	326.87	326.87
XS #50	326.28	326.29	326.29
XS #49	326.03	326.04	326.05
XS #48	325.78	325.78	325.80
XS #47	325.48	325.49	325.50
XS #46	325.30	325.31	325.32
XS #45	324.98	324.99	325.00
XS #44	324.42	324.44	324.45
XS #43	324.10	324.12	324.14
XS #42	323.76	323.78	323.80
XS #41	323.36	323.38	323.41
XS #40	322.98	323.00	323.03
XS #39	322.82	322.84	322.88
XS #38	322.66	322.69	322.73
XS #37	322.17	322.20	322.25
XS #36	322.06	322.10	322.15
XS #35	321.77	321.81	321.87
XS #34	321.73	321.77	321.83
XS #33	321.33	321.38	321.44
XS #32	320.60	320.66	320.74
XS #31	320.32	320.38	320.47
XS #30	320.13	320.20	320.29
XS #29	319.74	319.82	319.92
XS #28	319.71	319.79	319.89
XS #27	319.44	319.52	319.62
XS #26	319.43	319.51	319.61
XS #25	319.43	319.51	319.61

Table 24 Sensitivity analysis results for downstream boundary condition (continued)

Cross Section	100-Year Flood Levels (m) for Varying Downstream Boundary Condition		
	0.5 m Below Adopted S=0.000292 m/m	**Adopted Normal Depth S=0.00025 m/m**	**0.5 m Above Adopted S=0.000216 m/m**
Peace River			
XS #24	319.34	319.43	319.53
XS #23	319.38	319.46	319.57
XS #22	319.46	319.54	319.65
XS #21	319.42	319.51	319.62
XS #20	319.32	319.41	319.52
XS #19	318.86	318.95	319.07
XS #18	318.74	318.84	318.95
XS #17	318.36	318.47	318.60
XS #16	318.06	318.18	318.32
XS #15	317.71	317.85	318.00
XS #14	317.19	317.35	317.53
XS #13	316.97	317.14	317.33
XS #12	316.46	316.66	316.88
XS #11	316.15	316.37	316.61
XS #10	316.02	316.26	316.51
XS #09	315.41	315.67	315.97
XS #08	315.22	315.51	315.82
XS #07	315.12	315.42	315.73
XS #06	314.87	315.16	315.47
XS #05	314.63	314.94	315.27
XS #04	314.30	314.64	315.00
XS #03	314.01	314.39	314.79
XS #02	313.76	314.18	314.61
XS #01	313.19	313.69	314.19
Minimum Deviation	0.00	0.00	0.00
Average Deviation	-0.11	0.00	0.13
Maximum Deviation	-0.50	0.00	0.50

Table 24 Sensitivity analysis results for downstream boundary condition (continued)

Cross Section	100-Year Flood Levels (m) for Varying Downstream Boundary Condition		
	0.5 m Below Adopted S=0.000292 m/m	Adopted Normal Depth S=0.00025 m/m	0.5 m Above Adopted S=0.000216 m/m
Heart River			
XS #81	321.12	321.14	321.18
XS #80	320.91	320.95	321.00
XS #79	320.88	320.91	320.97
XS #78	320.78	320.82	320.88
XS #77	320.72	320.77	320.83
XS #76	320.68	320.72	320.79
XS #75	320.65	320.70	320.77
XS #74	320.63	320.68	320.75
XS #73	320.59	320.64	320.72
XS #72	320.57	320.62	320.70
XS #71	320.54	320.60	320.67
XS #70	320.53	320.58	320.66
XS #69	320.47	320.53	320.61
XS #68	320.47	320.52	320.61
XS #67	320.45	320.51	320.59
XS #66	320.44	320.50	320.58
XS #65	320.33	320.39	320.48
XS #64	320.33	320.39	320.48
XS #63	320.35	320.41	320.50
XS #62	320.34	320.40	320.49
XS #61	320.33	320.39	320.48
XS #60	320.33	320.39	320.48
XS #59	320.26	320.32	320.41
XS #58	320.23	320.29	320.38
XS #57	320.23	320.29	320.38
XS #56	320.23	320.29	320.38
XS #55	320.23	320.29	320.38
Minimum Deviation	-0.02	0.00	0.04
Average Deviation	-0.05	0.00	0.08
Maximum Deviation	-0.06	0.00	0.09

Table 25 Sensitivity analysis results for 95% confidence limits on Peace River 100-year discharge

Cross Section	100-Year Flood Levels (m) for 95% Confidence Limits		
	Lower Limit 13,800/18,900 m^3/s	Adopted Values 15,200/21,100 m^3/s	Upper Limit 17,100/24,200 m^3/s
Peace River			
XS #54	327.75	328.30	329.03
XS #53	327.13	327.69	328.43
XS #52	326.64	327.18	327.91
XS #51	326.33	326.87	327.59
XS #50	325.78	326.29	326.99
XS #49	325.52	326.04	326.76
XS #48	325.23	325.78	326.56
XS #47	324.92	325.49	326.29
XS #46	324.73	325.31	326.11
XS #45	324.38	324.99	325.83
XS #44	323.85	324.44	325.27
XS #43	323.53	324.12	325.00
XS #42	323.18	323.78	324.66
XS #41	322.77	323.38	324.30
XS #40	322.39	323.00	323.92
XS #39	322.22	322.84	323.79
XS #38	322.05	322.69	323.67
XS #37	321.51	322.20	323.24
XS #36	321.42	322.10	323.13
XS #35	321.11	321.81	322.87
XS #34	321.07	321.77	322.84
XS #33	320.64	321.38	322.49
XS #32	319.95	320.66	321.74
XS #31	319.69	320.38	321.46
XS #30	319.51	320.20	321.28
XS #29	319.15	319.82	320.86
XS #28	319.12	319.79	320.84
XS #27	318.85	319.52	320.56
XS #26	318.84	319.51	320.56
XS #25	318.84	319.51	320.56

Table 25 Sensitivity analysis results for 95% confidence limits on Peace River 100-year discharge (continued)

Cross Section	100-Year Flood Levels (m) for 95% Confidence Limits		
	Lower Limit 13,800/18,900 m³/s	Adopted Values 15,200/21,100 m³/s	Upper Limit 17,100/24,200 m³/s
Peace River			
XS #24	318.77	319.43	320.46
XS #23	318.79	319.46	320.52
XS #22	318.85	319.54	320.62
XS #21	318.80	319.51	320.61
XS #20	318.68	319.41	320.54
XS #19	318.26	318.95	320.02
XS #18	318.14	318.84	319.81
XS #17	317.77	318.47	319.45
XS #16	317.48	318.18	319.16
XS #15	317.14	317.85	318.83
XS #14	316.65	317.35	318.34
XS #13	316.44	317.14	318.12
XS #12	315.97	316.66	317.63
XS #11	315.68	316.37	317.34
XS #10	315.54	316.26	317.26
XS #09	315.01	315.67	316.62
XS #08	314.83	315.51	316.46
XS #07	314.75	315.42	316.36
XS #06	314.49	315.16	316.10
XS #05	314.29	314.94	315.86
XS #04	314.00	314.64	315.54
XS #03	313.74	314.39	315.31
XS #02	313.52	314.18	315.12
XS #01	313.03	313.69	314.62
Minimum Deviation	-0.51	0.00	0.70
Average Deviation	-0.65	0.00	0.95
Maximum Deviation	-0.74	0.00	1.13
Heart River			
XS #81	320.96	321.14	321.75

Table 25 Sensitivity analysis results for 95% confidence limits on Peace River 100-year discharge (continued)

Cross Section	100-Year Flood Levels (m) for 95% Confidence Limits		
	Lower Limit 13,800/18,900 m³/s	Adopted Values 15,200/21,100 m³/s	Upper Limit 17,100/24,200 m³/s
Heart River			
XS #80	320.64	320.95	321.68
XS #79	320.57	320.91	321.68
XS #78	320.42	320.82	321.64
XS #77	320.32	320.77	321.62
XS #76	320.25	320.72	321.60
XS #75	320.20	320.70	321.59
XS #74	320.17	320.68	321.59
XS #73	320.10	320.64	321.57
XS #72	320.06	320.62	321.56
XS #71	320.03	320.60	321.55
XS #70	320.01	320.58	321.54
XS #69	319.90	320.53	321.52
XS #68	319.90	320.52	321.52
XS #67	319.87	320.51	321.51
XS #66	319.86	320.50	321.50
XS #65	319.71	320.39	321.41
XS #64	319.71	320.39	321.42
XS #63	319.74	320.41	321.43
XS #62	319.72	320.40	321.43
XS #61	319.70	320.39	321.42
XS #60	319.70	320.39	321.42
XS #59	319.64	320.32	321.38
XS #58	319.61	320.29	321.37
XS #57	319.60	320.29	321.37
XS #56	319.60	320.29	321.37
XS #55	319.60	320.29	321.37
Minimum Deviation	-0.18	0.00	0.61
Average Deviation	-0.57	0.00	0.95
Maximum Deviation	-0.69	0.00	1.08

5.6.2 Manning's Roughness

The sensitivity of the calibrated model to Manning's roughness was evaluated. Channel roughness, which was primarily derived from calibration to observed water levels for high and low flow events, was examined independently of overbank (i.e. floodplain) roughness. Also, the sensitivity of the calibrated channel roughness on the Heart River reach was examined separately from the Peace River reach. The results of the sensitivity analysis are discussed below.

Channel Roughness

The calibrated channel roughness on the Peace River reach was 0.022 above WSC gauge 07HA001 and 0.024 from the gauge to the downstream model boundary. A plausible range of channel roughness for this reach of the Peace River was considered to be 0.020 to 0.028. For the low and high roughness sensitivity runs, a single channel roughness value was used along the entire reach as there is no apparent physical justification to further constrain the range of plausible values.

Table 26 provides the 100-year flood levels for low, calibrated, and high channel roughness on the Peace River at each cross section. Water surface profiles for each case are presented in **Figure 17**. On average, computed water levels were 0.85 and 0.76 m below calibrated levels for the Peace and Heart rivers, respectively, for a low channel roughness of 0.020. For the high roughness value of 0.028, computed water levels were 1.09 and 1.04 m above calibrated levels on average for the Peace and Heart rivers, respectively.

The calibrated channel roughness for the Heart River was 0.044. A plausible range of channel roughness values for this reach was considered to be 0.036 to 0.056, based on the channel size and characteristics. The high roughness value of 0.056 was considered to be fairly conservative and was chosen to demonstrate the relative effects of Heart River and Peace River channel roughness values on computed water levels. Computed flood levels on the Heart River were found to be dominated by computed 100-year flood levels on the Peace River; therefore, computed flood levels on the Heart River were not found to be sensitive to Heart River channel roughness, particularly within the most developed parts of TPR near the Heart River's confluence with the Peace River. **Table 27** provides the results of the analysis for varying Heart River channel roughness, using the calibrated Peace River channel roughness values. Water surface profiles for each case are presented in **Figure 18**. For the low channel roughness, the computed flood levels averaged 0.06 m below calibrated and at most 0.17 m below calibrated, with the largest deviations being in the most upstream part of the reach above the Heart River rail bridge. For the high channel roughness, the computed flood levels averaged 0.07 m above calibrated and at most 0.21 m above calibrated. Similarly, the largest deviations were found in the most upstream portion of the study reach extending beyond the area dominated by backwater flooding from the Peace River.

Table 26 Sensitivity analysis results for Peace River channel roughness

Cross Section	100-Year Flood Levels (m) for Varying Channel Roughness		
	Low Roughness n=0.020	Calibrated Roughness n=0.022/0.024	High Roughness n=0.028
Peace River			
XS #54	327.81	328.30	329.57
XS #53	327.15	327.69	329.02
XS #52	326.67	327.18	328.49
XS #51	326.36	326.87	328.15
XS #50	325.77	326.29	327.58
XS #49	325.53	326.04	327.29
XS #48	325.27	325.78	327.03
XS #47	324.97	325.49	326.72
XS #46	324.79	325.31	326.52
XS #45	324.43	324.99	326.24
XS #44	323.87	324.44	325.72
XS #43	323.54	324.12	325.41
XS #42	323.20	323.78	325.03
XS #41	322.80	323.38	324.60
XS #40	322.42	323.00	324.16
XS #39	322.27	322.84	323.94
XS #38	322.11	322.69	323.79
XS #37	321.53	322.20	323.33
XS #36	321.45	322.10	323.20
XS #35	321.11	321.81	322.93
XS #34	321.08	321.77	322.85
XS #33	320.61	321.38	322.49
XS #32	319.79	320.66	321.82
XS #31	319.47	320.38	321.53
XS #30	319.23	320.20	321.38
XS #29	318.82	319.82	320.92
XS #28	318.79	319.79	320.87
XS #27	318.49	319.52	320.61
XS #26	318.48	319.51	320.6
XS #25	318.48	319.51	320.59

Table 26 Sensitivity analysis results for Peace River channel roughness (continued)

Cross Section	100-Year Flood Levels (m) for Varying Channel Roughness		
	Low Roughness n=0.020	Calibrated Roughness n=0.022/0.024	High Roughness n=0.028
Peace River			
XS #24	318.36	319.43	320.53
XS #23	318.41	319.46	320.53
XS #22	318.52	319.54	320.58
XS #21	318.48	319.51	320.54
XS #20	318.34	319.41	320.47
XS #19	317.90	318.95	319.98
XS #18	317.85	318.84	319.73
XS #17	317.45	318.47	319.39
XS #16	317.16	318.18	319.11
XS #15	316.78	317.85	318.79
XS #14	316.28	317.35	318.32
XS #13	316.11	317.14	318.08
XS #12	315.58	316.66	317.64
XS #11	315.31	316.37	317.33
XS #10	315.24	316.26	317.19
XS #09	314.62	315.67	316.65
XS #08	314.47	315.51	316.47
XS #07	314.39	315.42	316.36
XS #06	314.13	315.16	316.11
XS #05	313.89	314.94	315.91
XS #04	313.57	314.64	315.62
XS #03	313.34	314.39	315.35
XS #02	313.12	314.18	315.15
XS #01	312.55	313.69	314.70
Average Deviation	-0.85	0.00	1.09
Maximum Deviation	-1.14	0.00	1.33
Heart River			
XS #81	320.92	321.14	321.82
XS #80	320.57	320.95	321.75
XS #79	320.48	320.91	321.75

Table 26 Sensitivity analysis results for Peace River channel roughness (continued)

Cross Section	100-Year Flood Levels (m) for Varying Channel Roughness		
	Low Roughness n=0.020	Calibrated Roughness n=0.022/0.024	High Roughness n=0.028
Heart River			
XS #78	320.33	320.82	321.72
XS #77	320.20	320.77	321.70
XS #76	320.12	320.72	321.68
XS #75	320.05	320.70	321.67
XS #74	320.00	320.68	321.66
XS #73	319.93	320.64	321.65
XS #72	319.88	320.62	321.64
XS #71	319.84	320.60	321.63
XS #70	319.82	320.58	321.62
XS #69	319.69	320.53	321.60
XS #68	319.68	320.52	321.60
XS #67	319.65	320.51	321.59
XS #66	319.64	320.50	321.58
XS #65	319.47	320.39	321.50
XS #64	319.47	320.39	321.50
XS #63	319.50	320.41	321.52
XS #62	319.48	320.40	321.51
XS #61	319.45	320.39	321.50
XS #60	319.45	320.39	321.50
XS #59	319.40	320.32	321.47
XS #58	319.36	320.29	321.46
XS #57	319.35	320.29	321.46
XS #56	319.35	320.29	321.46
XS #55	319.35	320.29	321.46
Average Deviation	-0.76	0.00	1.04
Maximum Deviation	-0.94	0.00	1.17

Table 27 Sensitivity analysis results for Heart River channel roughness

Cross Section	100-Year Flood Levels (m) for Varying Channel Roughness		
	Low Roughness n=0.036	Calibrated Roughness n=0.044	High Roughness n=0.056
Heart River			
XS #81	320.97	321.14	321.37
XS #80	320.79	320.95	321.15
XS #79	320.79	320.91	321.10
XS #78	320.71	320.82	320.99
XS #77	320.67	320.77	320.92
XS #76	320.63	320.72	320.86
XS #75	320.62	320.70	320.82
XS #74	320.60	320.68	320.80
XS #73	320.57	320.64	320.76
XS #72	320.55	320.62	320.73
XS #71	320.53	320.60	320.70
XS #70	320.53	320.58	320.68
XS #69	320.47	320.53	320.63
XS #68	320.47	320.52	320.61
XS #67	320.46	320.51	320.59
XS #66	320.46	320.50	320.57
XS #65	320.35	320.39	320.45
XS #64	320.36	320.39	320.45
XS #63	320.39	320.41	320.46
XS #62	320.38	320.40	320.44
XS #61	320.37	320.39	320.42
XS #60	320.37	320.39	320.42
XS #59	320.31	320.32	320.33
XS #58	320.29	320.29	320.31
XS #57	320.29	320.29	320.30
XS #56	320.29	320.29	320.29
XS #55	320.29	320.29	320.29
Average Deviation	-0.06	0.00	0.09
Maximum Deviation	-0.17	0.00	0.23

Overbank Roughness

The sensitivity of computed 100-year flood levels to overbank roughness was evaluated by selecting low and high roughness coefficients for each of the three overbank landcover types identified in **Table 13**. Considering values published by Chow (1959) and seasonal variations in vegetation growth and density, plausible low values for lightly and densely vegetated areas were 0.036 and 0.060, respectively. Plausible high values for lightly and densely vegetated areas were 0.10 and 0.15, respectively. As the developed urban areas were relatively small in area (proportional to the total study area), consisted of mostly low density residential and commercial development, and were bounded by flood protection dykes, roughness values used for these urban areas were equivalent to those for densely vegetated areas in all cases. The sensitivity analysis was run concurrently for the Peace River and Heart River reaches, unlike the channel roughness sensitivity analysis described above.

Table 28 presents the results of the 100-year computed flood level sensitivity analysis for varying overbank roughness values. Water surface profiles for each case are presented in **Figure 19**. On average, flood levels were 0.11 and 0.13 m below calibrated values for low overbank roughness on the Peace and Heart rivers, respectively. For high overbank roughness, computed flood levels were 0.23 and 0.31 m above calibrated values for the Peace and Heart rivers, respectively. The largest deviations of 0.36 to 0.38 m from calibrated flood levels were found for the high overbank roughness case.

Table 28 Sensitivity analysis results for overbank roughness

Cross Section	100-Year Flood Levels (m) for Varying Overbank Roughness		
	Low Roughness n=0.036/0.060	Adopted Roughness n=0.060/0.080	High Roughness n=0.10/0.15
Peace River			
XS #54	328.27	328.30	328.36
XS #53	327.65	327.69	327.76
XS #52	327.14	327.18	327.26
XS #51	326.82	326.87	326.96
XS #50	326.24	326.29	326.39
XS #49	325.99	326.04	326.16
XS #48	325.72	325.78	325.92
XS #47	325.43	325.49	325.64
XS #46	325.24	325.31	325.46
XS #45	324.92	324.99	325.16
XS #44	324.36	324.44	324.63
XS #43	324.03	324.12	324.34
XS #42	323.67	323.78	324.02
XS #41	323.27	323.38	323.67

Table 28 Sensitivity analysis results for overbank roughness (continued)

Cross Section	100-Year Flood Levels (m) for Varying Overbank Roughness		
	Low Roughness n=0.036/0.060	Adopted Roughness n=0.060/0.080	High Roughness n=0.10/0.15
Peace River			
XS #40	322.87	323.00	323.32
XS #39	322.70	322.84	323.19
XS #38	322.55	322.69	323.03
XS #37	322.05	322.20	322.53
XS #36	321.95	322.10	322.43
XS #35	321.64	321.81	322.18
XS #34	321.60	321.77	322.15
XS #33	321.22	321.38	321.73
XS #32	320.54	320.66	320.93
XS #31	320.25	320.38	320.67
XS #30	320.06	320.20	320.50
XS #29	319.66	319.82	320.15
XS #28	319.63	319.79	320.13
XS #27	319.35	319.52	319.86
XS #26	319.34	319.51	319.85
XS #25	319.34	319.51	319.85
XS #24	319.26	319.43	319.78
XS #23	319.30	319.46	319.81
XS #22	319.38	319.54	319.88
XS #21	319.34	319.51	319.85
XS #20	319.23	319.41	319.77
XS #19	318.80	318.95	319.22
XS #18	318.72	318.84	319.00
XS #17	318.36	318.47	318.64
XS #16	318.08	318.18	318.36
XS #15	317.75	317.85	318.03
XS #14	317.25	317.35	317.54
XS #13	317.05	317.14	317.32
XS #12	316.60	316.66	316.83
XS #11	316.31	316.37	316.53

Table 28 Sensitivity analysis results for overbank roughness (continued)

Cross Section	100-Year Flood Levels (m) for Varying Overbank Roughness		
	Low Roughness n=0.036/0.060	Adopted Roughness n=0.060/0.080	High Roughness n=0.10/0.15
Peace River			
XS #10	316.19	316.26	316.44
XS #09	315.60	315.67	315.88
XS #08	315.44	315.51	315.68
XS #07	315.35	315.42	315.57
XS #06	315.09	315.16	315.32
XS #05	314.87	314.94	315.10
XS #04	314.57	314.64	314.81
XS #03	314.33	314.39	314.50
XS #02	314.14	314.18	314.25
XS #01	313.64	313.69	313.76
Average Deviation	-0.11	0.00	0.23
Maximum Deviation	-0.18	0.00	0.38
Heart River			
XS #81	321.04	321.14	321.46
XS #80	320.83	320.95	321.27
XS #79	320.80	320.91	321.23
XS #78	320.69	320.82	321.16
XS #77	320.64	320.77	321.11
XS #76	320.59	320.72	321.08
XS #75	320.56	320.70	321.06
XS #74	320.54	320.68	321.02
XS #73	320.51	320.64	320.99
XS #72	320.49	320.62	320.93
XS #71	320.47	320.60	320.88
XS #70	320.46	320.58	320.86
XS #69	320.41	320.53	320.82
XS #68	320.40	320.52	320.80
XS #67	320.39	320.51	320.79
XS #66	320.38	320.50	320.78
XS #65	320.26	320.39	320.68

Table 28 Sensitivity analysis results for overbank roughness (continued)

Cross Section	100-Year Flood Levels (m) for Varying Overbank Roughness		
	Low Roughness n=0.036/0.060	Adopted Roughness n=0.060/0.080	High Roughness n=0.10/0.15
Heart River			
XS #64	320.26	320.39	320.68
XS #63	320.28	320.41	320.70
XS #62	320.27	320.40	320.70
XS #61	320.26	320.39	320.68
XS #60	320.26	320.39	320.68
XS #59	320.19	320.32	320.61
XS #58	320.17	320.29	320.59
XS #57	320.16	320.29	320.59
XS #56	320.16	320.29	320.59
XS #55	320.16	320.29	320.59
Average Deviation	-0.13	0.00	0.31
Maximum Deviation	-0.14	0.00	0.36

6 CONCLUSIONS

The objectives of this study were to assess river flood-related hazards along a 54 km reach of the Peace river and a 1.1 km reach of the Heart River that includes the Town of Peace River. The Peace River Hazard Study was divided into nine major project components. This report summarizes the work of the ***Hydraulic Model Creation and Calibration*** component, for which a numerical model has been developed using the HEC-RAS computer program from the U.S. Army Corps of Engineers. River bathymetry and digital terrain data from the ***Survey and Base Data Collection*** component as well as flood frequency estimates from the ***Open Water Hydrology Assessment*** component have been used to develop, calibrate, and apply the open water hydraulic model as described throughout this report. The reports for the two previous work components mentioned above should also be read in conjunction with this report, as they provide additional pertinent background information.

Open water flooding has occurred on the Peace River, most notably at the Town of Peace River where the largest concentration of population and infrastructure exists within the study reach. Floods on the Peace River have historically caused direct overbank flooding (prior to construction of the Peace River flood control dykes) and highwater on the Heart River within the lower townsite due to backwater effects from the Peace River. The largest recorded flood event was the June 1990 flood, which had an estimated peak discharge of 18,545 m^3/s and was associated with concurrent highwater events on both the Peace and Smoky rivers. This event was adopted for model calibration due both to its relative magnitude and the number of highwater mark observations available along the study reach to support model calibration. Results of the June 1990 calibration show that the open water hydraulic model computed water levels that agreed with the observed highwater marks, with the average difference between modelled and observed being 0.01 m and the greatest differences being 0.31 m below and 0.58 m above the observed highwater marks.

Water surface profiles were prepared for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water flood frequency return period discharges on the Peace River. These profiles indicate that the deck elevations for bridges crossing the Peace River are well above the 1000-year flood level, with the bottom chord for the left and right portions of the CPR bridge being just above the 500-year open water flood level. On the Heart River, the low chord of the 101 Street bridge is situated the lowest, just above the 10-year (Peace River backwater) flood level. The crest of the flood control dykes on both the east and west side of the Peace River through town generally sit about 0.95 m above the 100-year open water flood level and would be expected to be overtopped at multiple locations for the 200-year and larger flood events.

Sensitivity of simulated water levels to various model parameters was also investigated. Discharge and Peace River channel roughness were shown to have greater effect on predicted 100-year flood levels than downstream boundary condition or overbank roughness within a range of plausible values. For Peace River floods, flood levels on the Heart River were not sensitive to Heart River channel roughness values due to the dominance of backwater from the Peace River within short Heart River study reach.

Based on the available data, calibration results, and sensitivity analysis, the open water HEC-RAS hydraulic model produces reliable water levels throughout the study reach for a wide range of discharges up to the 1000-year return period event. Results have also been shown to be consistent with the Water Survey of Canada rating curve at the Town of Peace River. The model includes all pertinent physical features, flood control structures, and the most up-to-date bathymetry and terrain data available as at the time of writing of this report. As such, the calibrated HEC-RAS model is considered appropriate for use in the subsequent open water inundation mapping and flood hazard identification components of this Peace River Hazard Study.

7 REFERENCES

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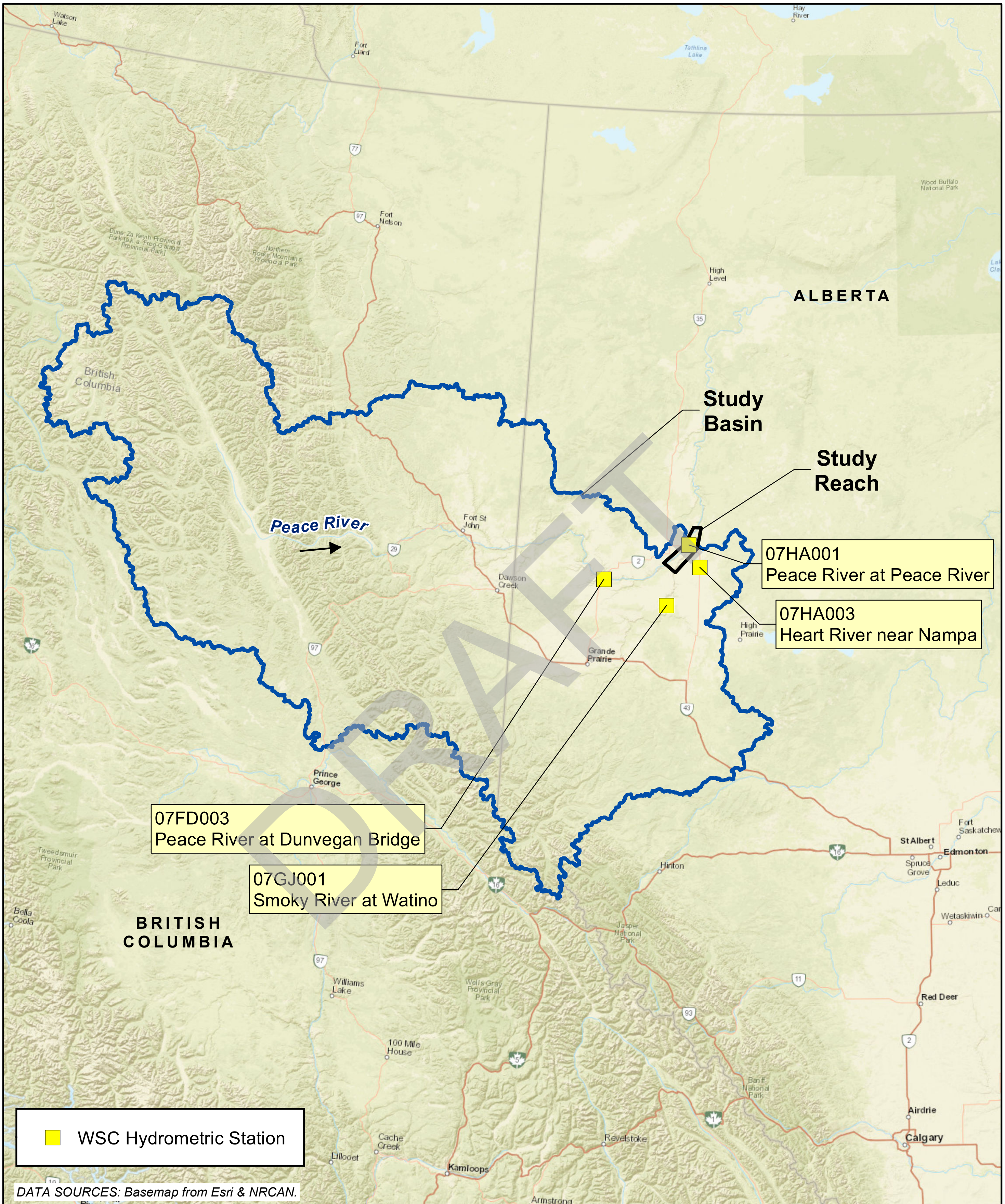
Figures



Alberta Government

SCALE - 1:5,000,000

0 100 200 KM

N

PEACE RIVER HAZARD STUDY

HYDRAULIC MODEL CREATION AND CALIBRATION

LOCATION MAP

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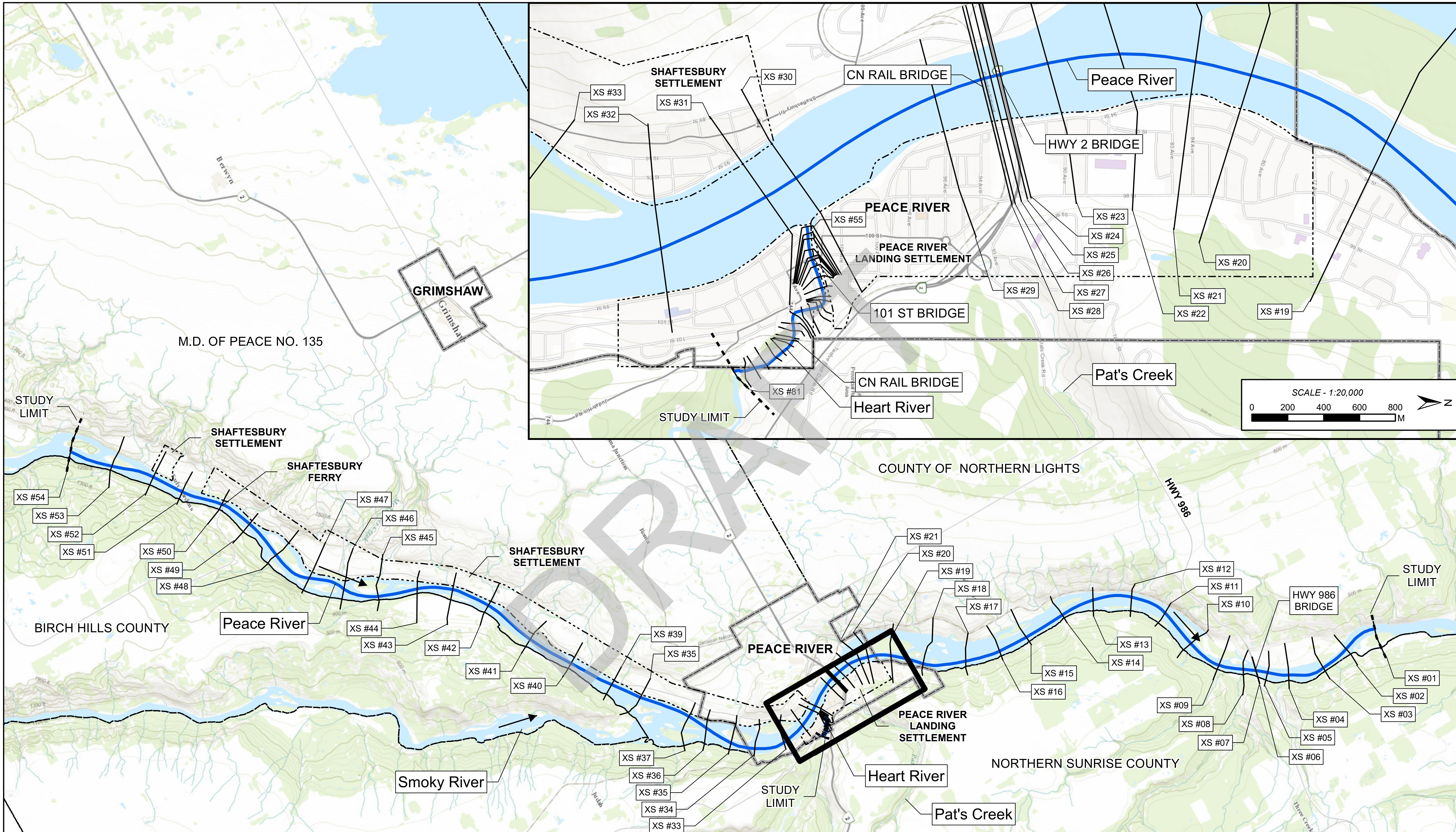
Coordinate System: NAD 1983 CSRS 10TM AEP FOREST
Units: METRES

Job: 1001119 | Date: 23-JUN-2017

FIGURE 1

MSN, \\mainfile-van\Projects\Active\1001119 Peace River Flood Hazard Study\GIS\1001119_MSN_Fig_T300_LocnMap3.mxd

Classification: Public



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Model Stream Network
Model Cross Section
Settlement
Town
County or Municipal District

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:130,000
0 1 2 3 4 5 KM

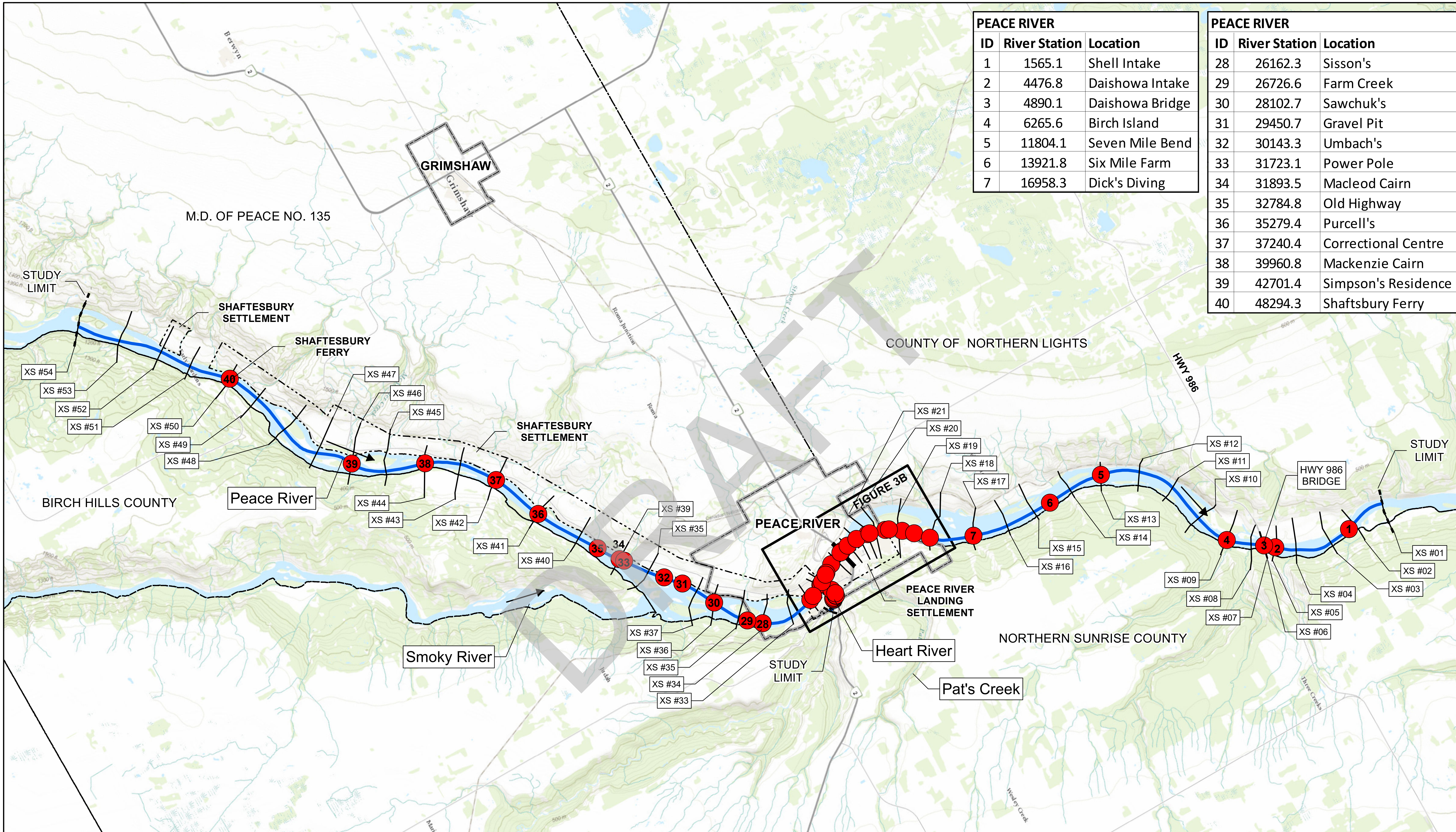
Coordinate System: NAD 1983 CSRS 3TM 117
Units: METRES

Job: 1001119 Date: 23-JUN-2017

PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION
STUDY AREA

FIGURE 2

MSN_\\nanfile-van\Projects\Active\1001119 Peace River Flood Hazard Study\GIS\1001119_MSN_Fig_T300_StudyAreaB3.mxd



PEACE RIVER		
ID	River Station	Location
1	1565.1	Shell Intake
2	4476.8	Daishowa Intake
3	4890.1	Daishowa Bridge
4	6265.6	Birch Island
5	11804.1	Seven Mile Bend
6	13921.8	Six Mile Farm
7	16958.3	Dick's Diving

PEACE RIVER		
ID	River Station	Location
28	26162.3	Sisson's
29	26726.6	Farm Creek
30	28102.7	Sawchuk's
31	29450.7	Gravel Pit
32	30143.3	Umbach's
33	31723.1	Power Pole
34	31893.5	Macleod Cairn
35	32784.8	Old Highway
36	35279.4	Purcell's
37	37240.4	Correctional Centre
38	39960.8	Mackenzie Cairn
39	42701.4	Simpson's Residence
40	48294.3	Shaftsbury Ferry

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Model Stream Network
Model Cross Section
Highwater Mark
Settlement
Town
County or Municipal District

Highwater marks are presented along the river centreline to show their approximate locations along the study reach. Precise measurement locations are unknown for most highwater mark observations.

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:130,000

0 1 2 3 4 5 KM

Coordinate System: NAD 1983 CSRS 3TM 117
Units: METRES

Job: 1001119 Date: 23-JUN-2017

PEACE RIVER HAZARD STUDY

HYDRAULIC MODEL CREATION AND CALIBRATION

HIGHWATER MARK LOCATIONS

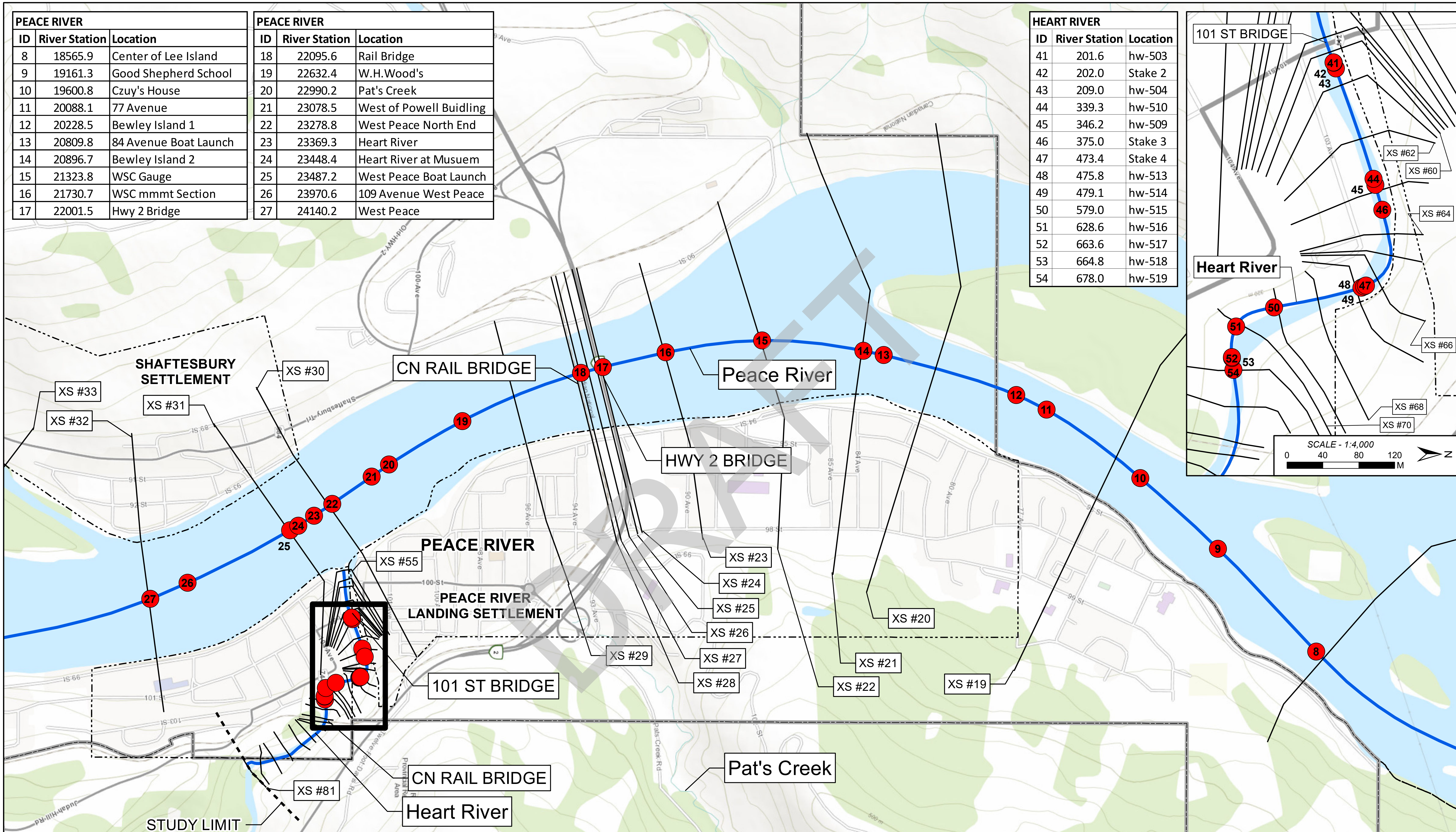
FIGURE 3A

MSN, \\nanfile-van\Projects\Active\1001119 Peace River Flood Hazard Study\GIS\1001119_MSN_Fig_T300_HWM4_Sheet1.mxd

PEACE RIVER		
ID	River Station	Location
8	18565.9	Center of Lee Island
9	19161.3	Good Shepherd School
10	19600.8	Czuy's House
11	20088.1	77 Avenue
12	20228.5	Bewley Island 1
13	20809.8	84 Avenue Boat Launch
14	20896.7	Bewley Island 2
15	21323.8	WSC Gauge
16	21730.7	WSC mmmt Section
17	22001.5	Hwy 2 Bridge

PEACE RIVER		
ID	River Station	Location
18	22095.6	Rail Bridge
19	22632.4	W.H.Wood's
20	22990.2	Pat's Creek
21	23078.5	West of Powell Buidling
22	23278.8	West Peace North End
23	23369.3	Heart River
24	23448.4	Heart River at Musuem
25	23487.2	West Peace Boat Launch
26	23970.6	109 Avenue West Peace
27	24140.2	West Peace

HEART RIVER		
ID	River Station	Location
41	201.6	hw-503
42	202.0	Stake 2
43	209.0	hw-504
44	339.3	hw-510
45	346.2	hw-509
46	375.0	Stake 3
47	473.4	Stake 4
48	475.8	hw-513
49	479.1	hw-514
50	579.0	hw-515
51	628.6	hw-516
52	663.6	hw-517
53	664.8	hw-518
54	678.0	hw-519



Model Stream Network
Model Cross Section
Highwater Mark
Settlement
Town
County or Municipal District

Highwater marks are presented along the river centreline to show their approximate locations along the study reach. Precise measurement locations are unknown for most highwater mark observations.

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:15,000

0 100 200 300 400 500 600 M

Coordinate System: NAD 1983 CSRS 3TM 117
Units: METRES

Job: 1001119 *Date: 23-JUN-2017*

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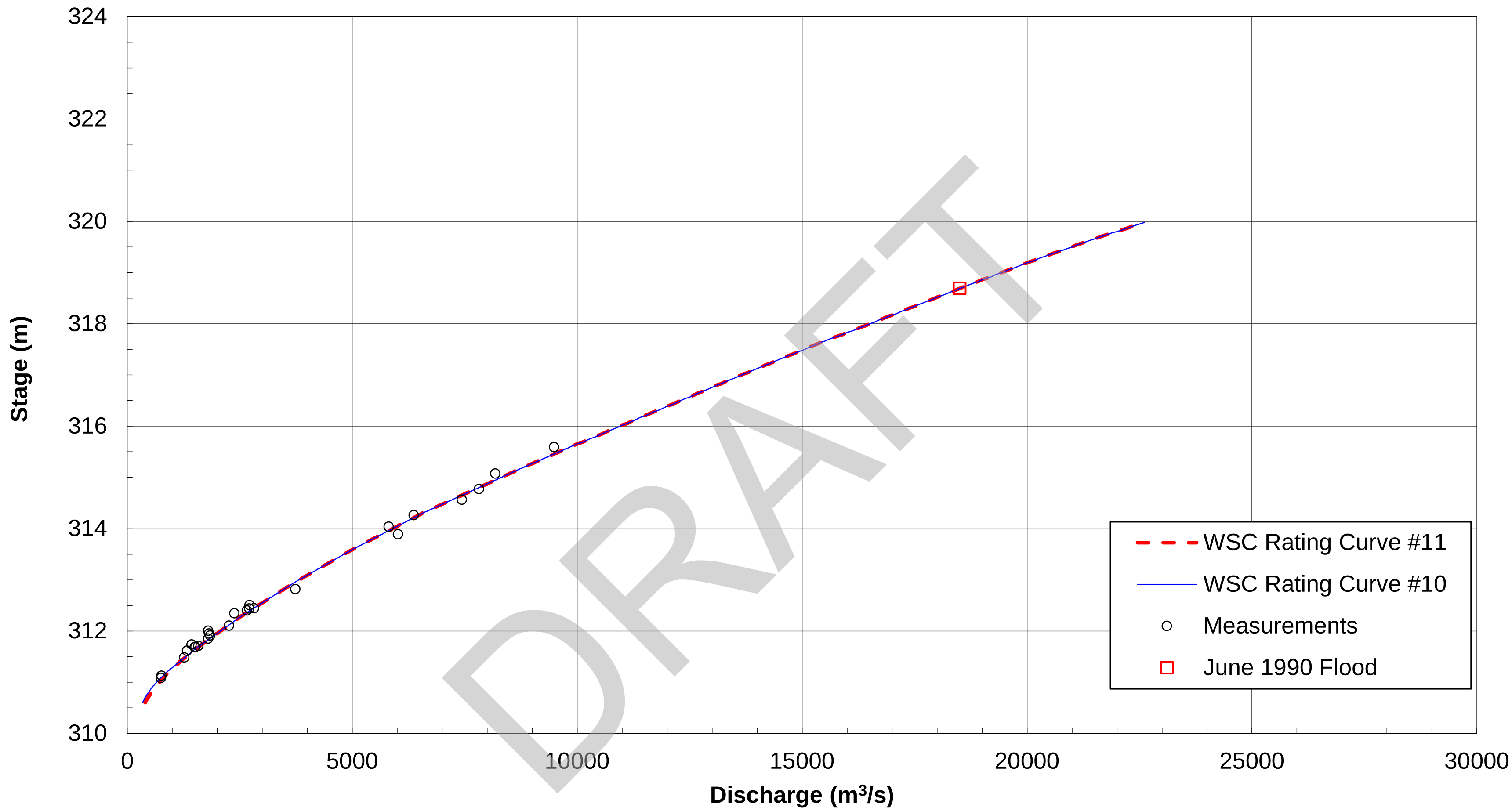
PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION
HIGHWATER MARK LOCATIONS

FIGURE 3B



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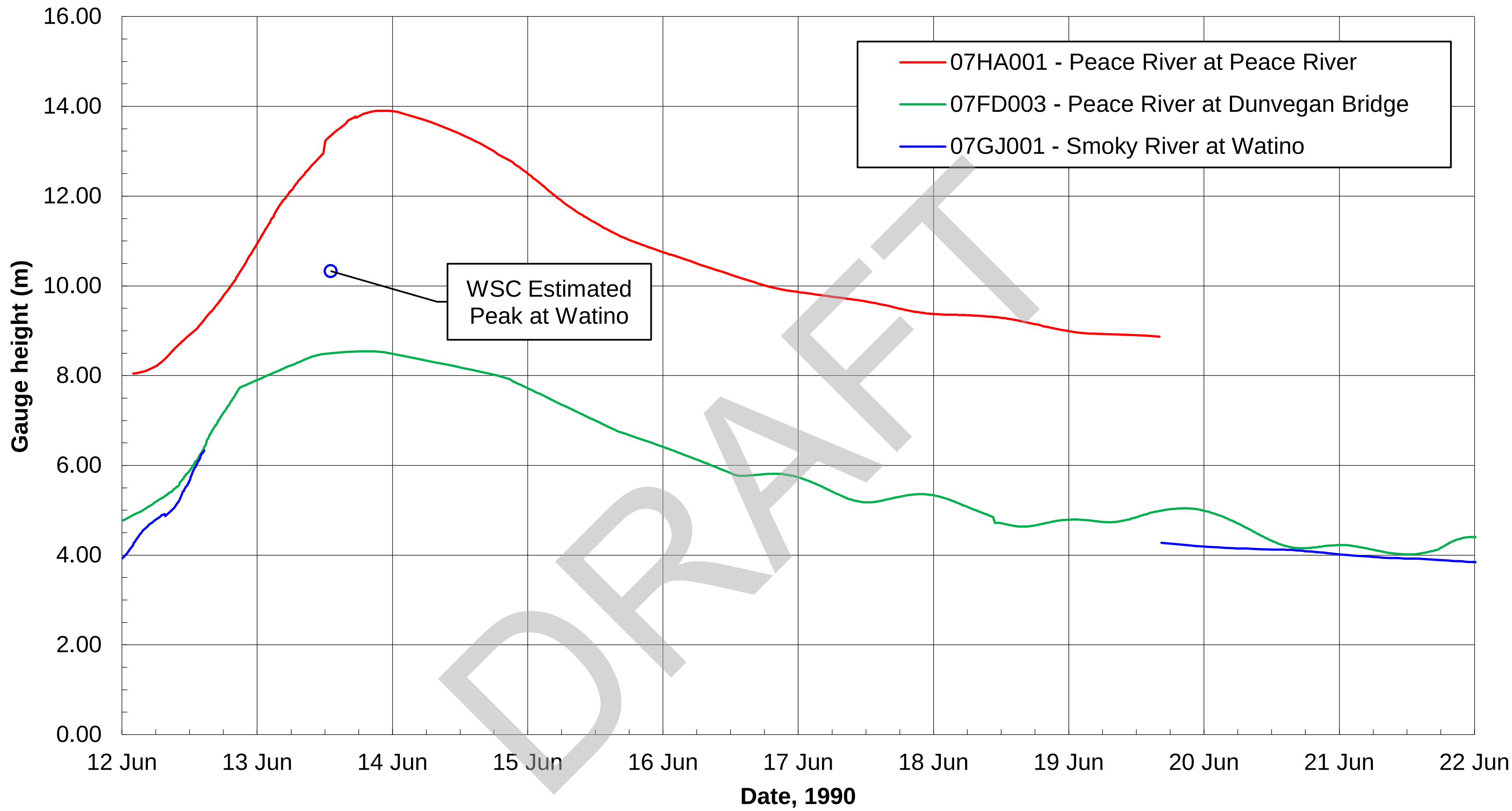
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURVEY OF CANADA RATING CURVE** **07HA001 – PEACE RIVER AT PEACE RIVER**		
1001119	23 JUN 2017	**FIGURE 4**



ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **JUNE 1990 GAUGE MEASUREMENTS ON THE PEACE AND SMOKY RIVERS**		
1001119	23 JUN 2017	**FIGURE 5**

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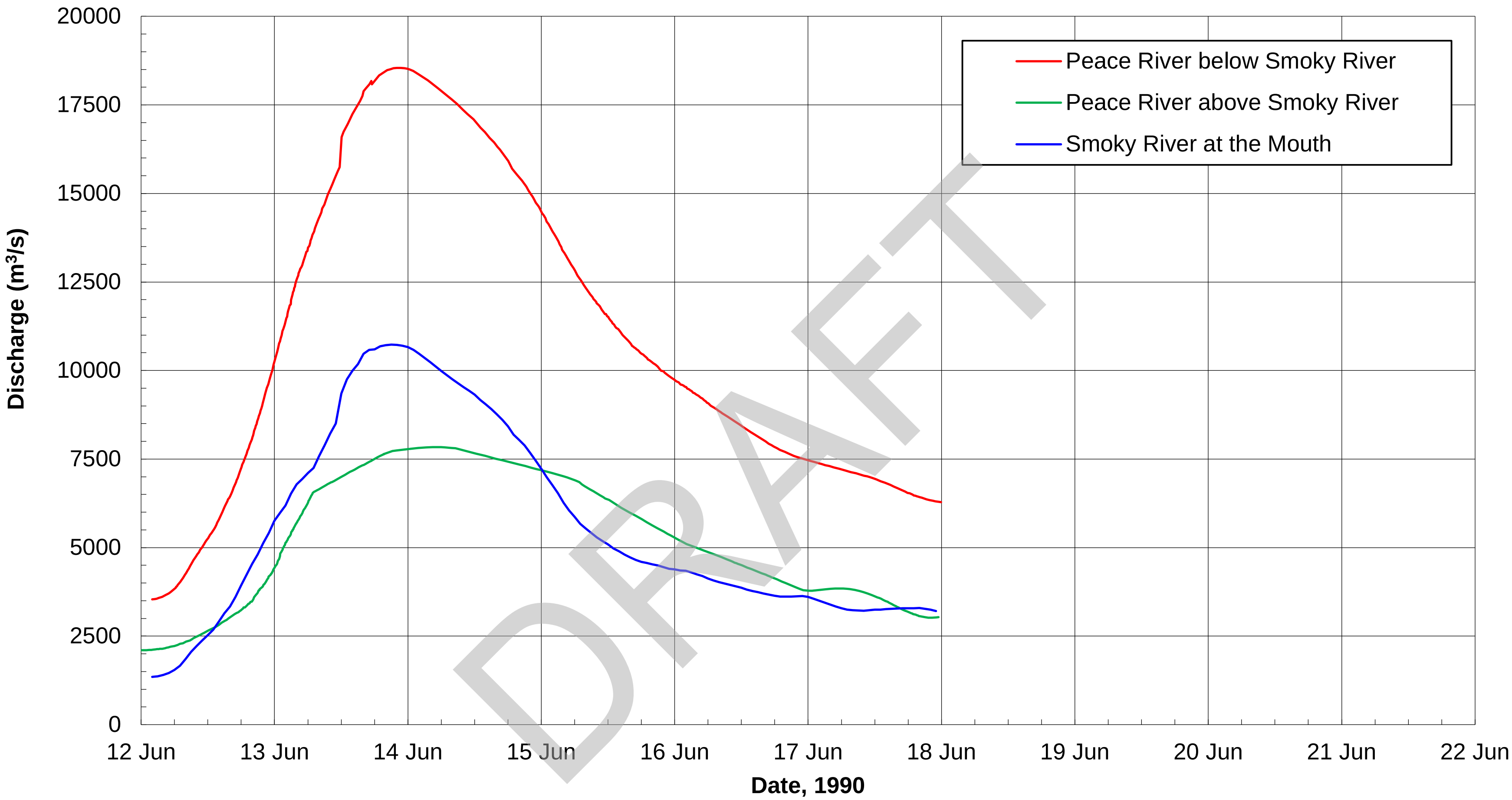
Classification: Public



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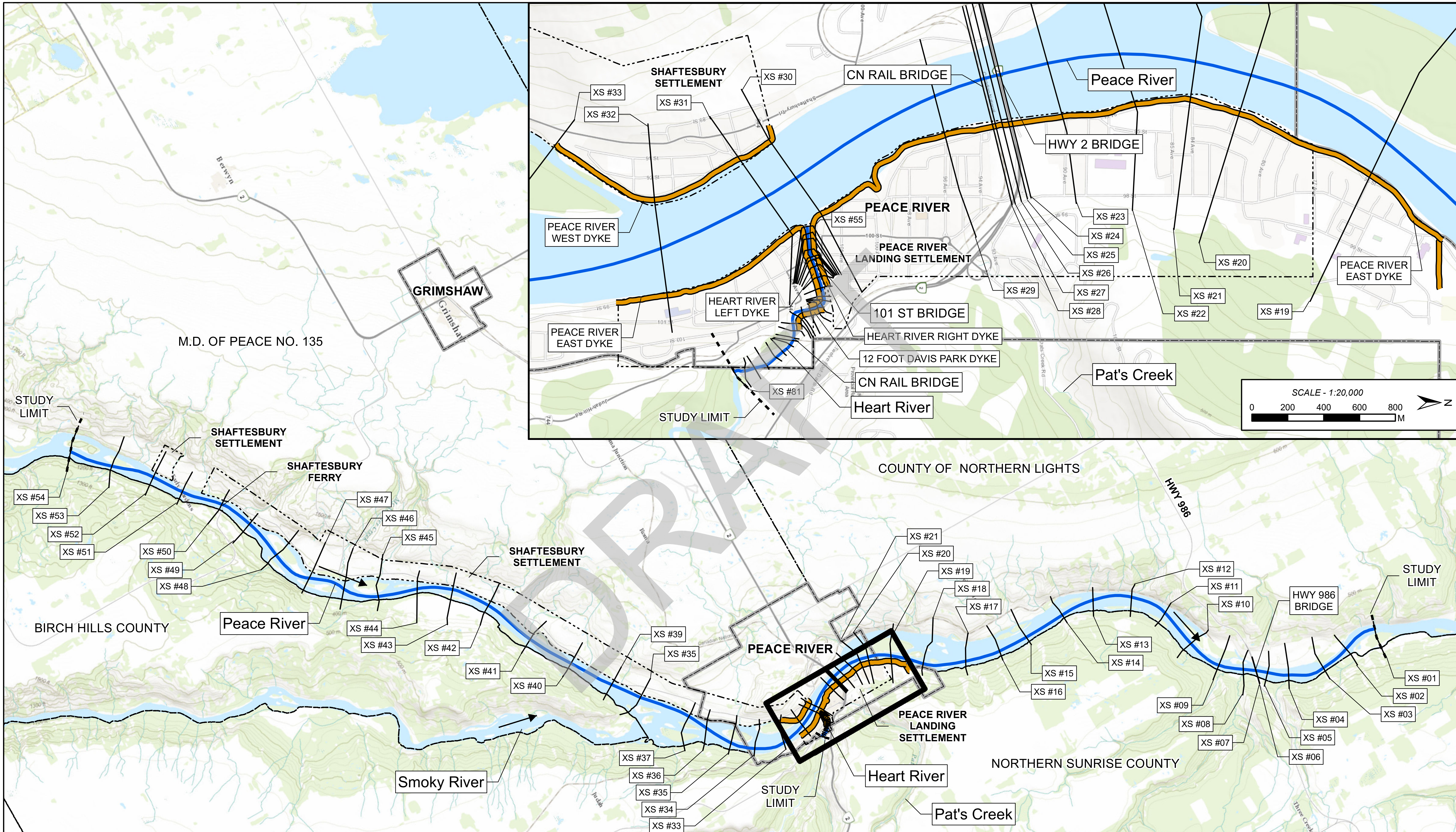
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **1990 DISCHARGE HYDROGRAPHS ADJUSTED FOR TRAVEL TIME TO TOWN OF PEACE RIVER**		
1001119	23 JUN 2017	**FIGURE 6**

Classification: Public



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Model Stream Network
Model Cross Section
Flood Control Structure
Settlement
Town
County or Municipal District

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:130,000

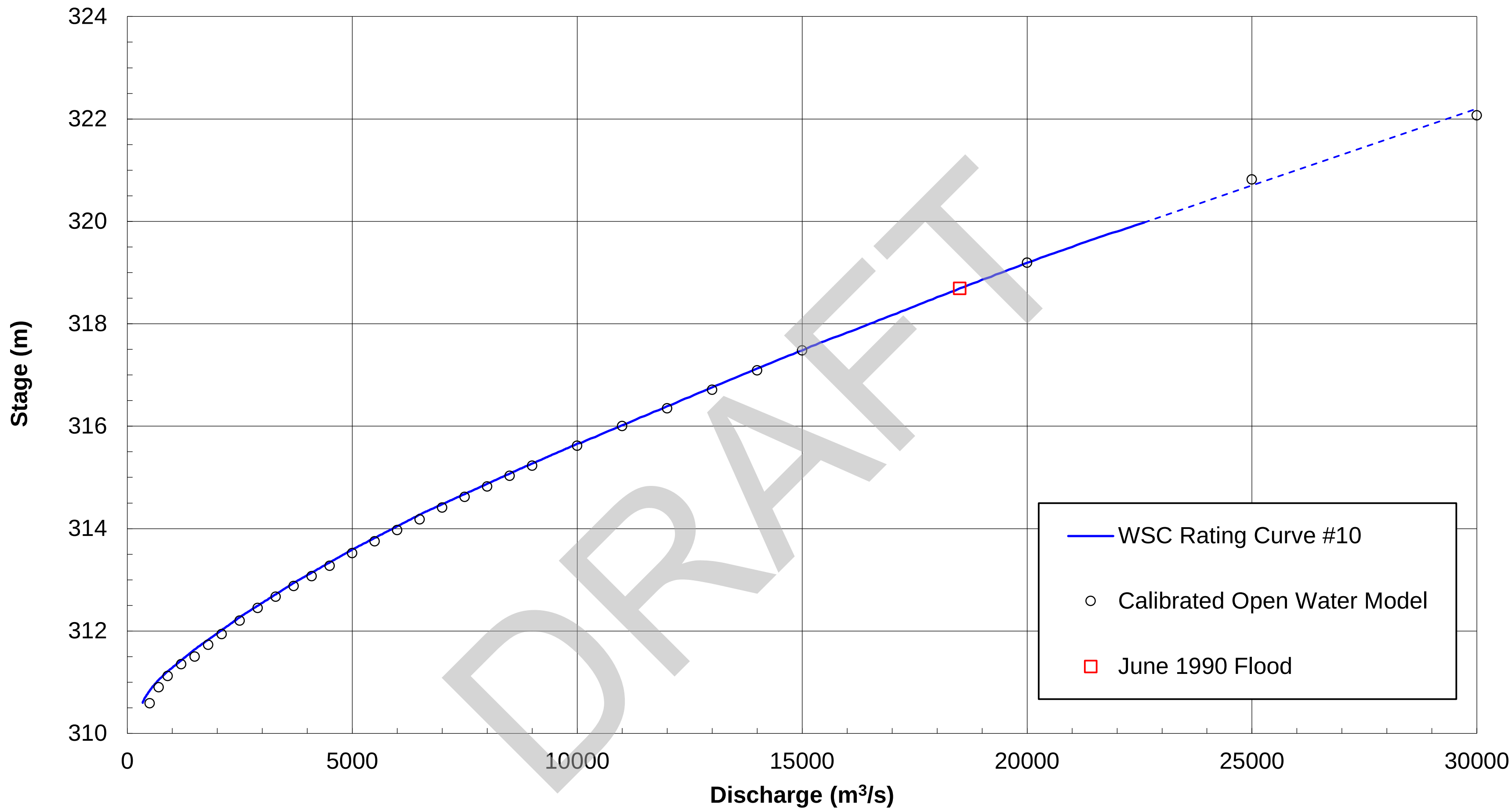
0 1 2 3 4 5 KM

N

Coordinate System: NAD 1983 CSRS 3TM 117
Units: METRES

Job: 1001119 *Date: 23-JUN-2017*

PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION
FLOOD CONTROL STRUCTURE LOCATIONS AND EXTENTS
FIGURE 7



Notes: 1. Dashed line indicates an extrapolation of WSC rating curve #10 to illustrate the calibrated model agreement at 25,000 and 30,000 m^3/s.

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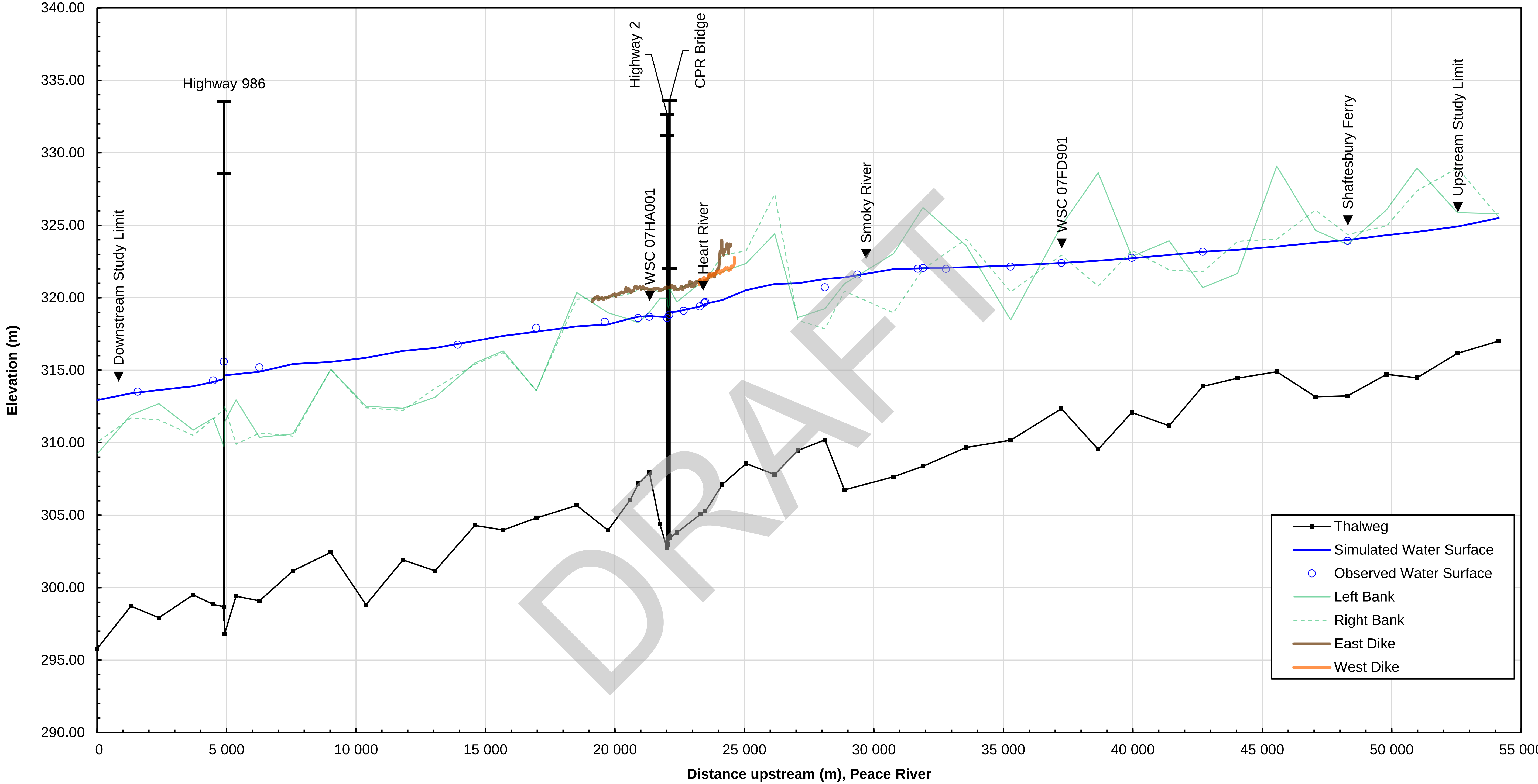
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPARISON OF SIMULATED RATING CURVE TO GAUGE RATING CURVE 07HA001 – PEACE RIVER AT PEACE RIVER**		
1001119	23 JUN 2017	**FIGURE 8**



Notes: 1. Peak instantaneous discharges

- 18,545 m³/s Peace River at Peace River (07HA001)
- 10,815 m³/s Smoky River at the mouth
- 7,730 m³/s Peace River above Smoky River

2. Mean difference between simulated and observed water level is -0.01 m (excluding observed highwater mark at Highway 986 Bridge, which is considered suspect).

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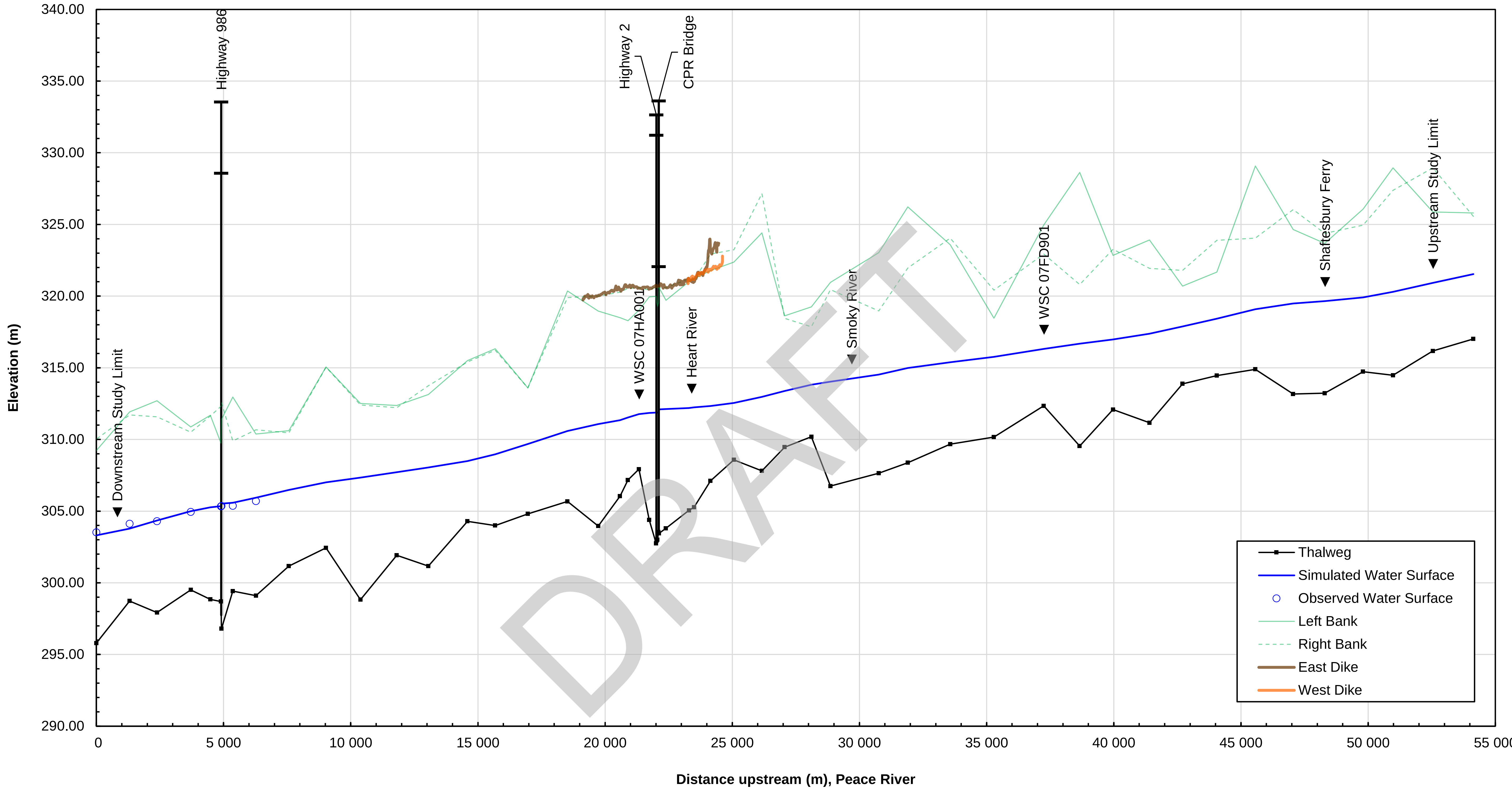
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURFACE PROFILE CALIBRATION 1990 FLOOD**		
1001119	23 JUN 2017	**FIGURE 9**



Notes:
1. Discharge derived from WSC gauge records for 19 October 2016
   - Peace River at Peace River (07HA001) = 1,857 m3/s
   - Smoky River at the Mouth = 161 m3/s
2. Mean difference between simulated and observed water level is 0.03 m (day) and 0.02 m (overall)

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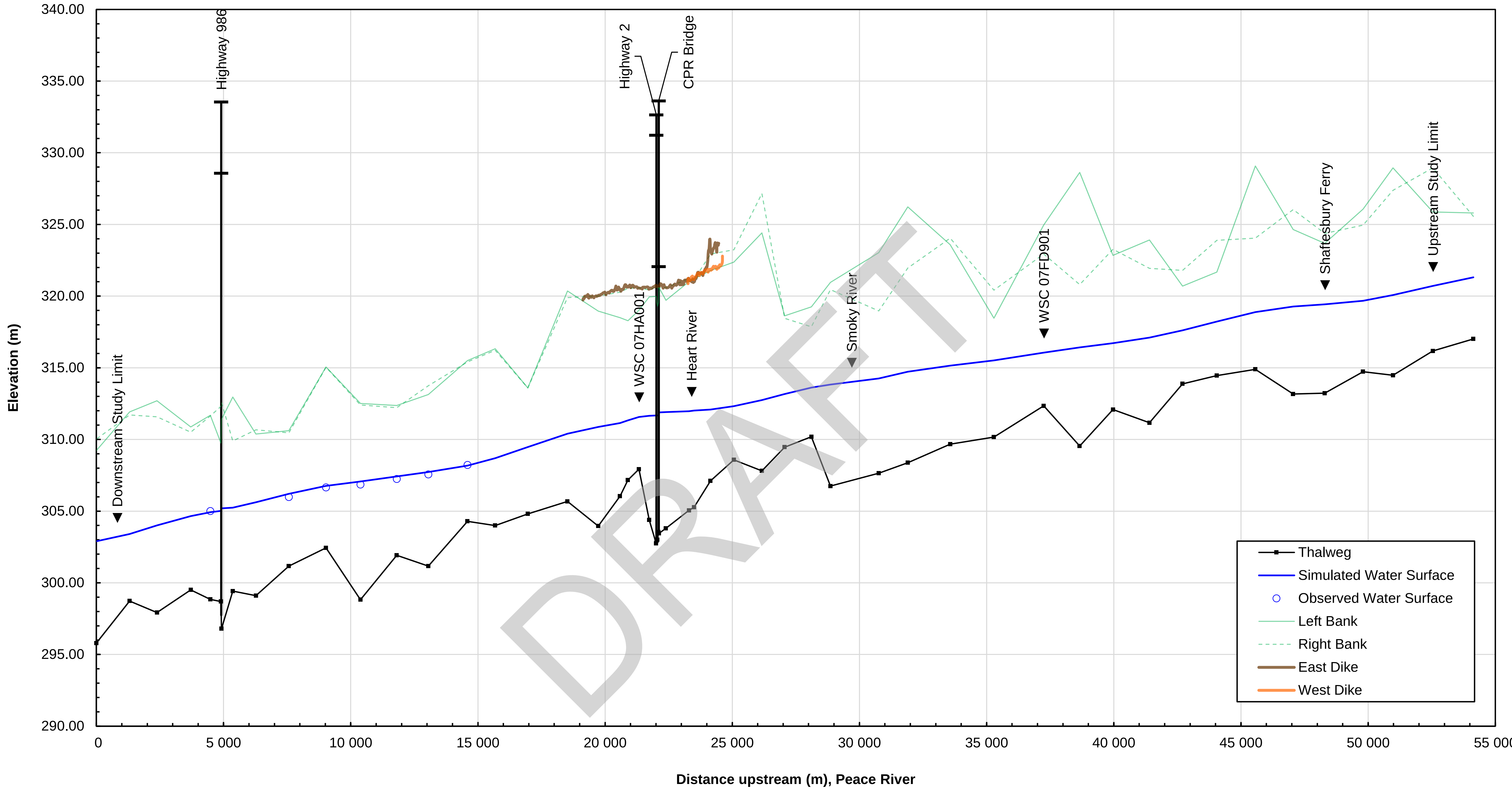
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURFACE PROFILE CALIBRATION** **2015 OPEN WATER SURVEY – 19 OCT 2015**		
1001119	23 JUN 2017	**FIGURE 10A**



Notes:
1. Discharge derived from WSC gauge records for 20 October 2016
   - Peace River at Peace River (07HA001) = 1,585 m3/s
   - Smoky River at the Mouth = 156 m3/s
2. Mean difference between simulated and observed water level is 0.10 m (day) and 0.02 m (overall)

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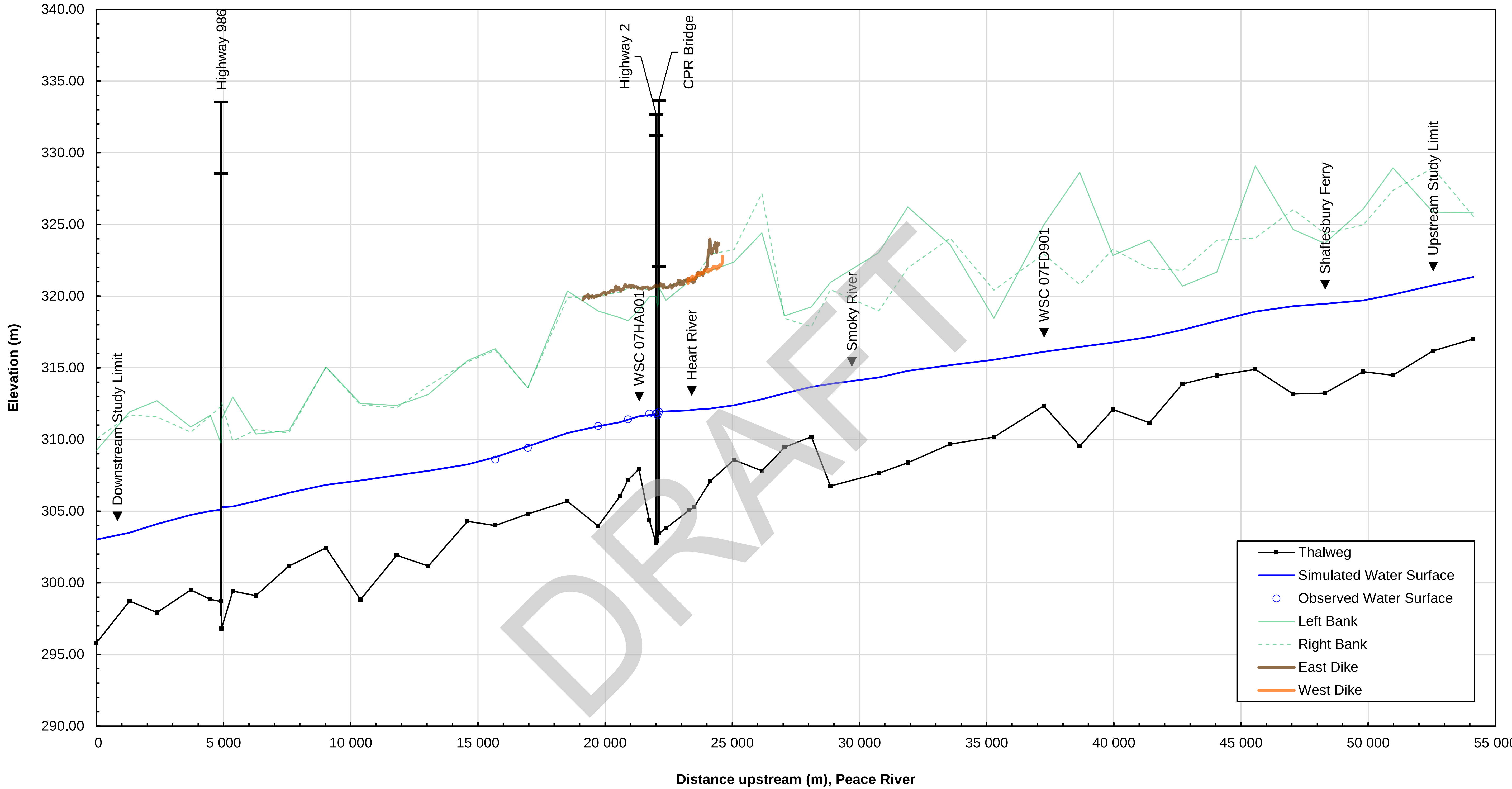
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURFACE PROFILE CALIBRATION 2015 OPEN WATER SURVEY – 20 OCT 2015**		
1001119	23 JUN 2017	**FIGURE 10B**

Classification: Public



Notes:
1. Discharge derived from WSC gauge records for 21 October 2016
   - Peace River at Peace River (07HA001) = 1,653 m3/s
   - Smoky River at the Mouth = 157 m3/s
2. Mean difference between simulated and observed water level is 0.10 m (day) and 0.02 m (overall)

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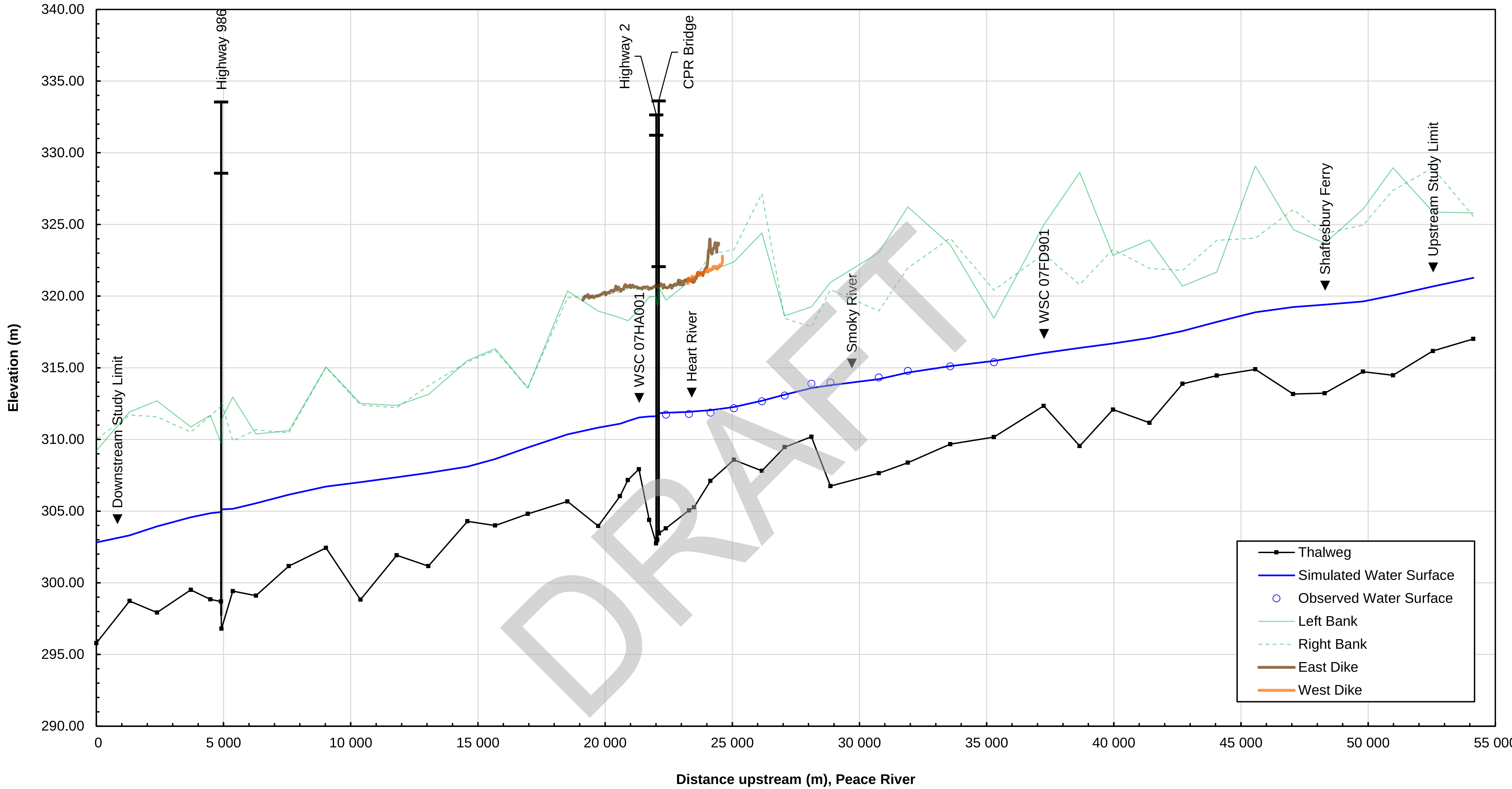
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURFACE PROFILE CALIBRATION** **2015 OPEN WATER SURVEY – 21 OCT 2015**		
1001119	23 JUN 2017	**FIGURE 10C**



Notes: 1. Discharge derived from WSC gauge records for 22 October 2016
- Peace River at Peace River (07HA001) = 1,527 m3/s
- Smoky River at the Mouth = 152 m3/s

2. Mean difference between simulated and observed water level is 0.03 m (day) and 0.02 m (overall)

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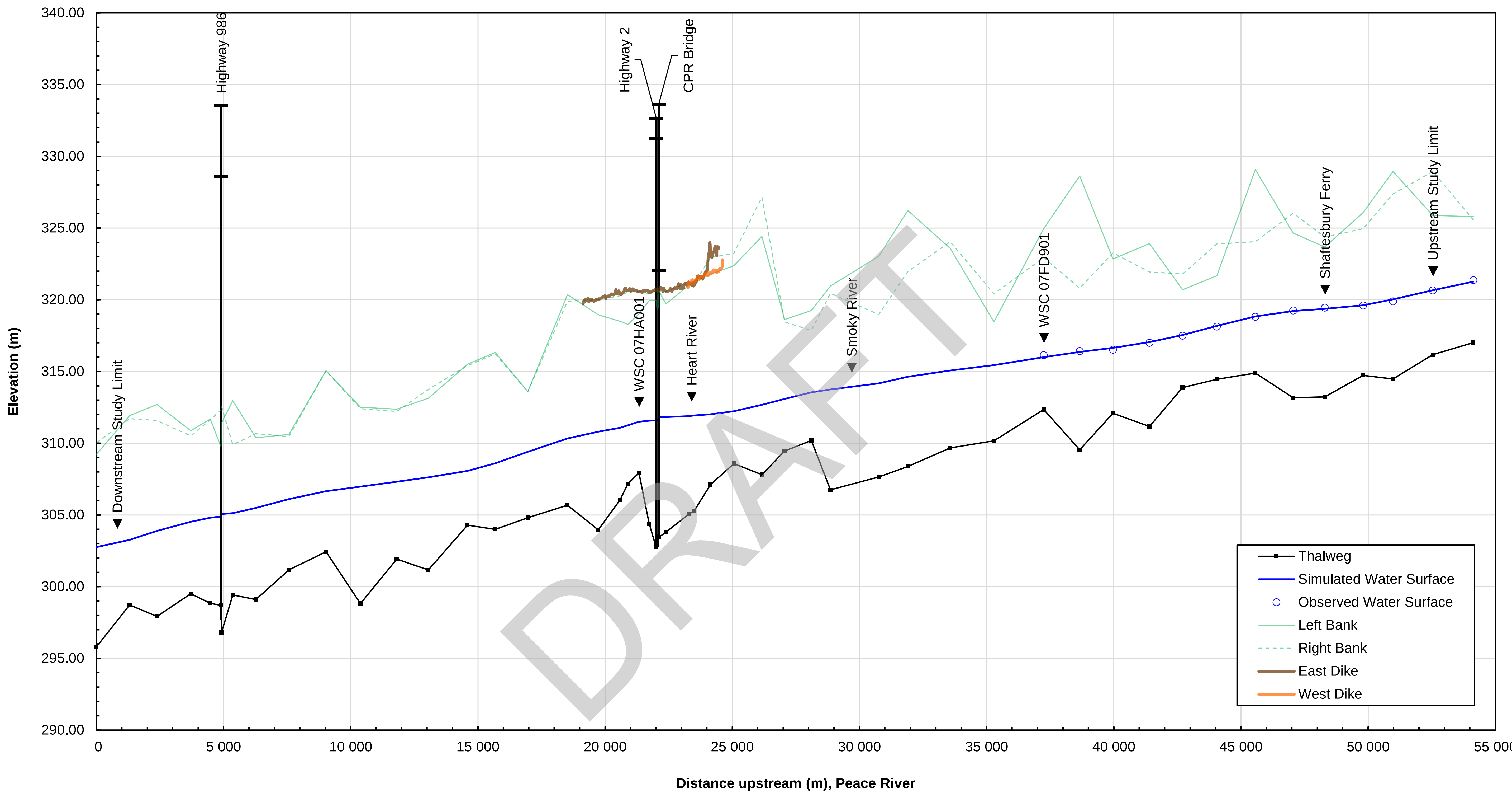
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURFACE PROFILE CALIBRATION** **2015 OPEN WATER SURVEY – 22 OCT 2015**		
1001119	23 JUN 2017	**FIGURE 10D**



Notes:
1. Discharge derived from WSC gauge records for 23 October 2016
   - Peace River at Peace River (07HA001) = 1,481 m3/s
   - Smoky River at the Mouth = 149 m3/s
2. Mean difference between simulated and observed water level is 0.01 m (day) and 0.02 m (overall)

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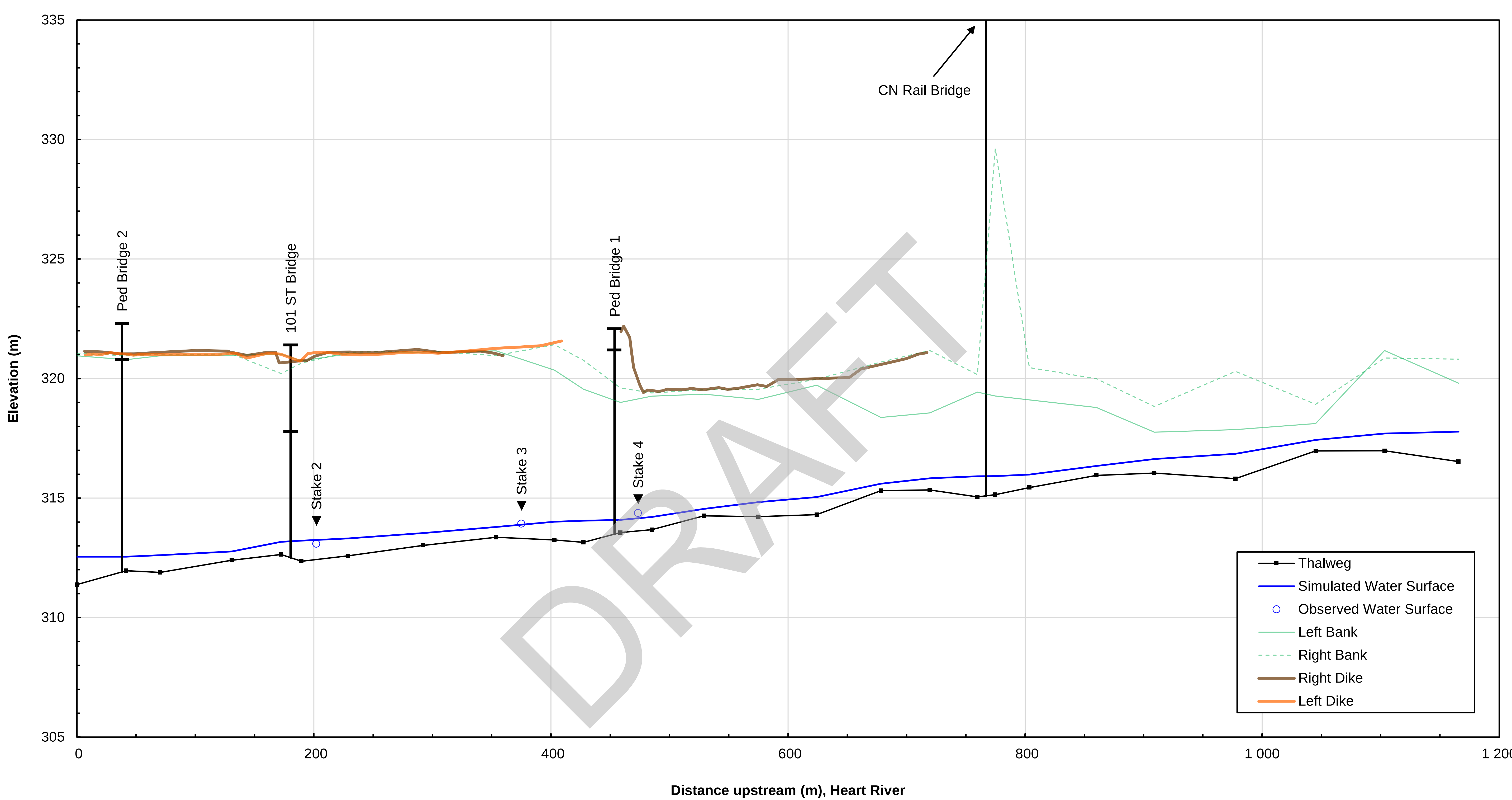
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **WATER SURFACE PROFILE CALIBRATION** **2015 OPEN WATER SURVEY – 23 OCT 2015**		
1001119	23 JUN 2017	**FIGURE 10E**

Classification: Public



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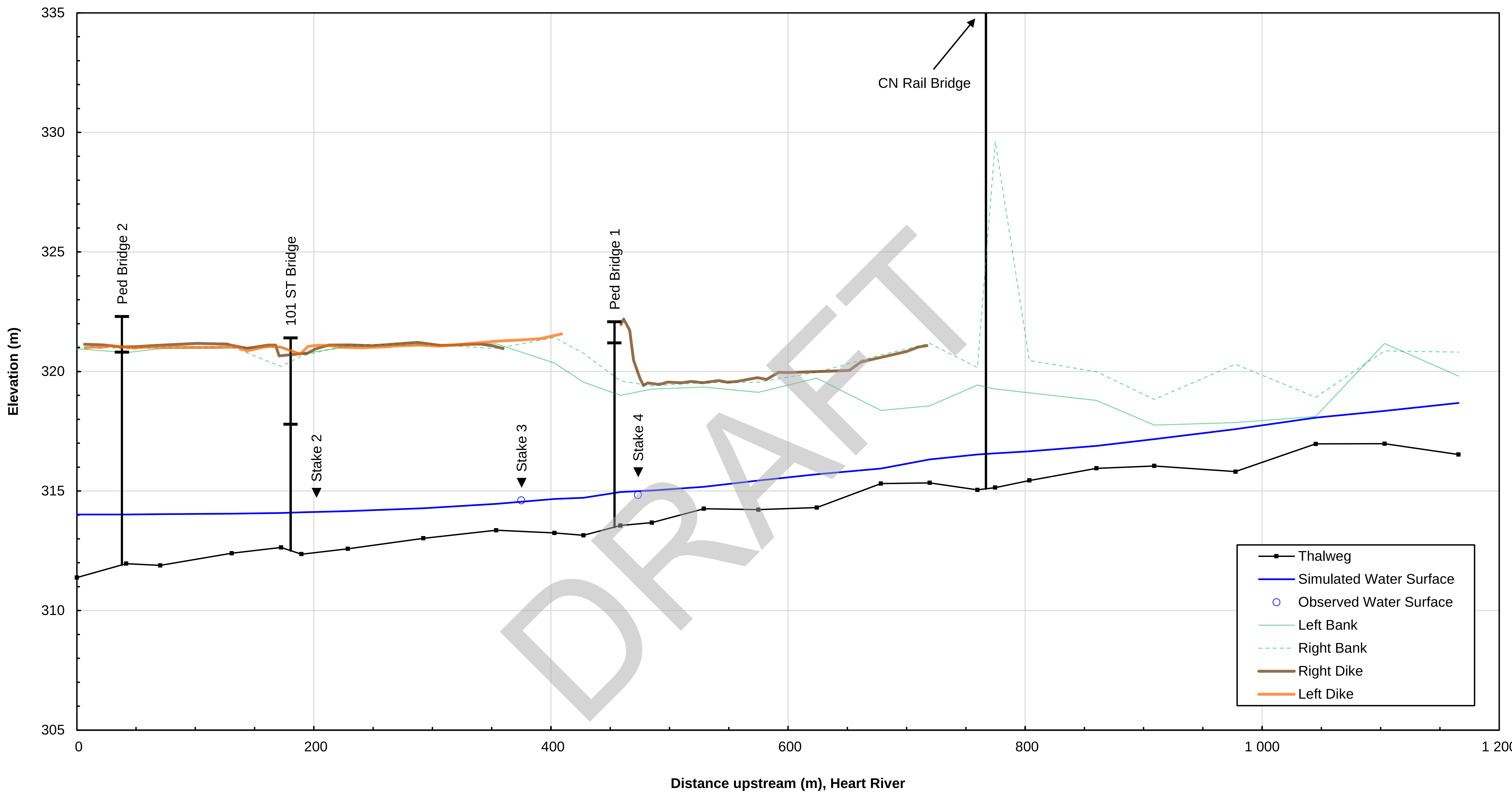
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HEART RIVER** **WATER SURFACE PROFILE CALIBRATION** **2016 HIGHWATER MARKS – 3 JUNE 2016**		
1001119	23 JUN 2017	**FIGURE 11A**



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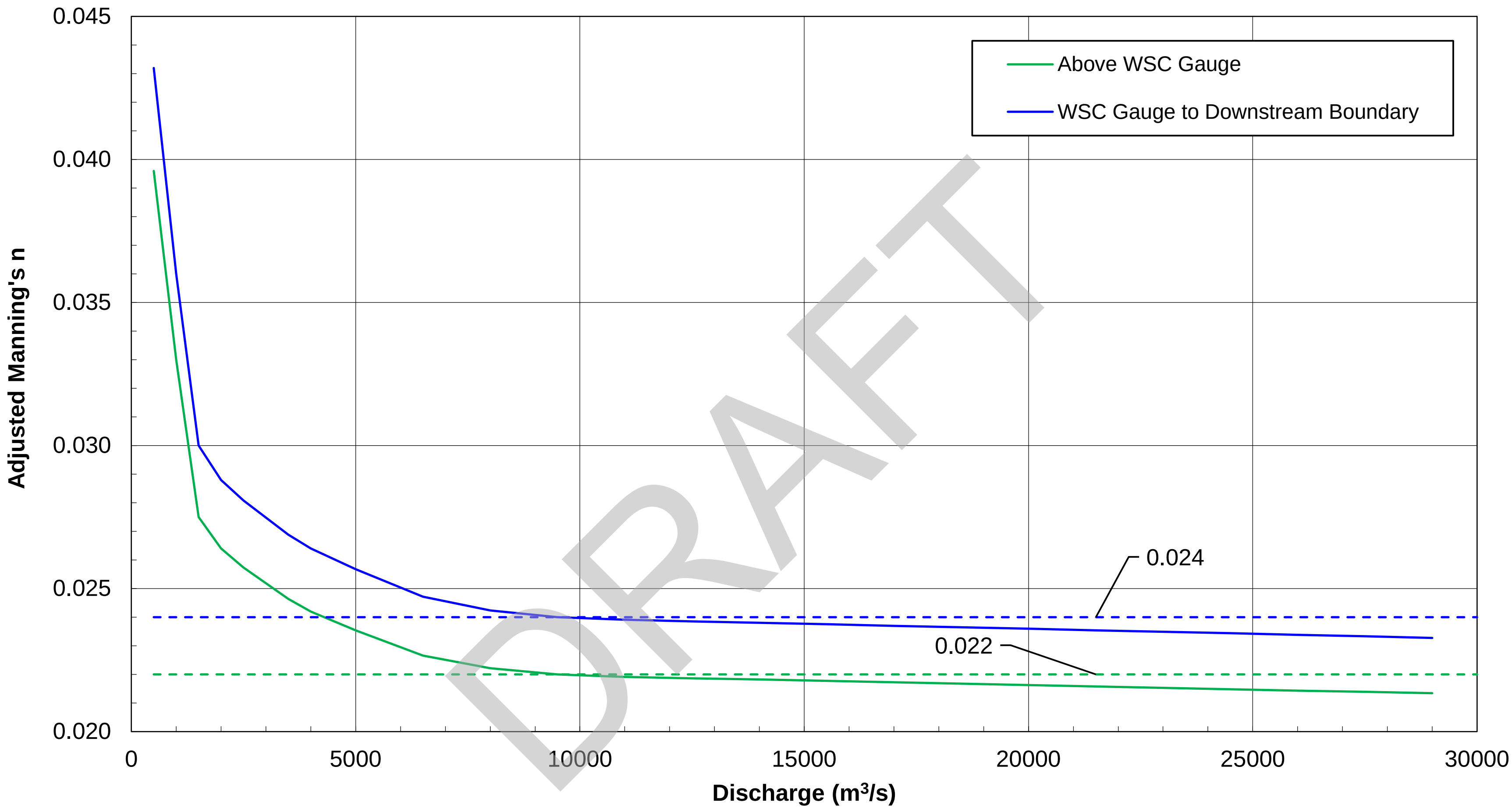
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HEART RIVER** **WATER SURFACE PROFILE CALIBRATION** **2016 HIGHWATER MARKS – 20 JUNE 2016**		
1001119	23 JUN 2017	**FIGURE 11B**



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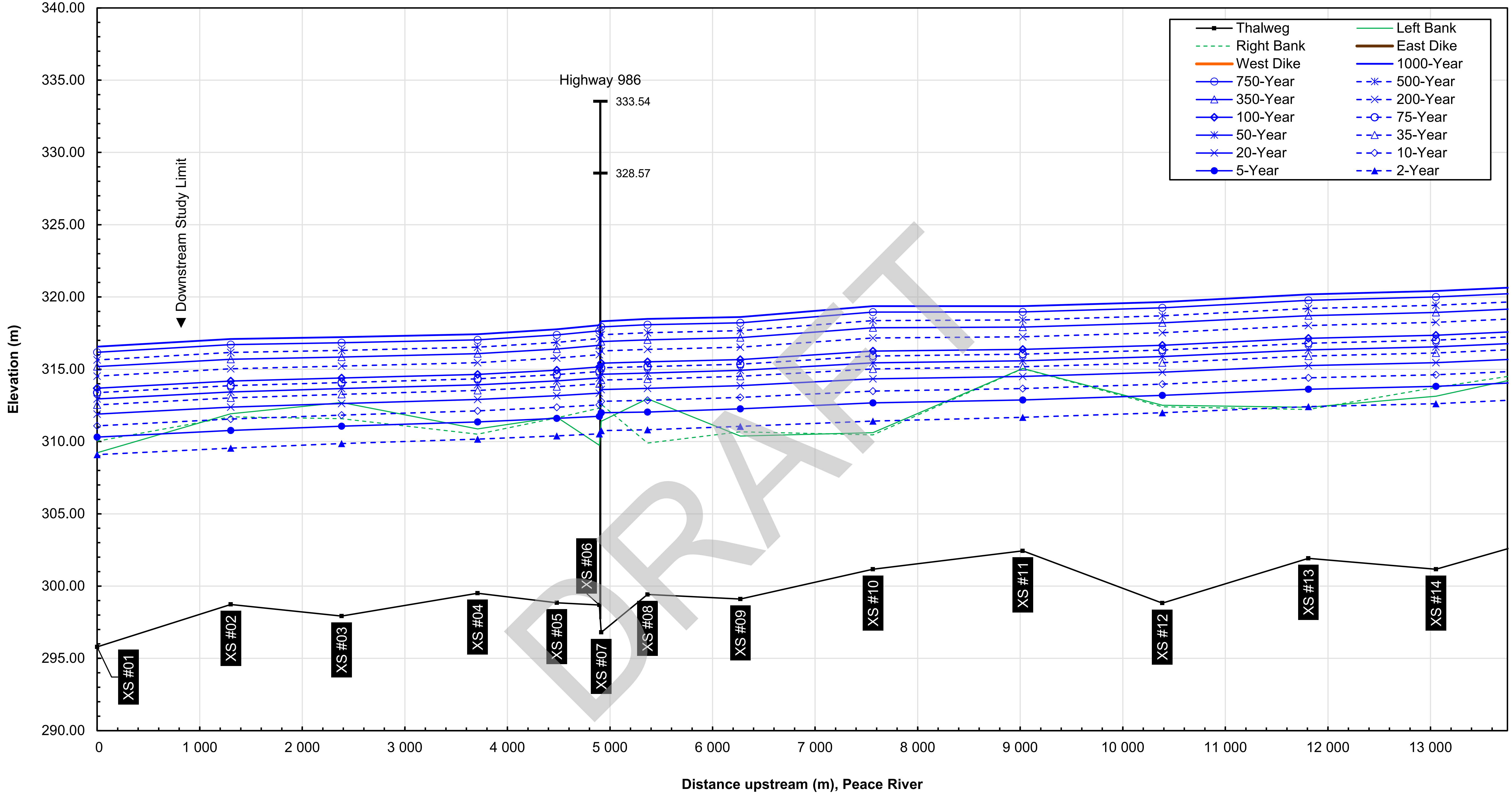
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **VARIATION OF CHANNEL ROUGHNESS WITH DISCHARGE BASED ON CALIBRATION TO GAUGE RATING CURVE**		
1001119	23 JUN 2017	**FIGURE 12**

Classification: Public



Revised 30 December 2019

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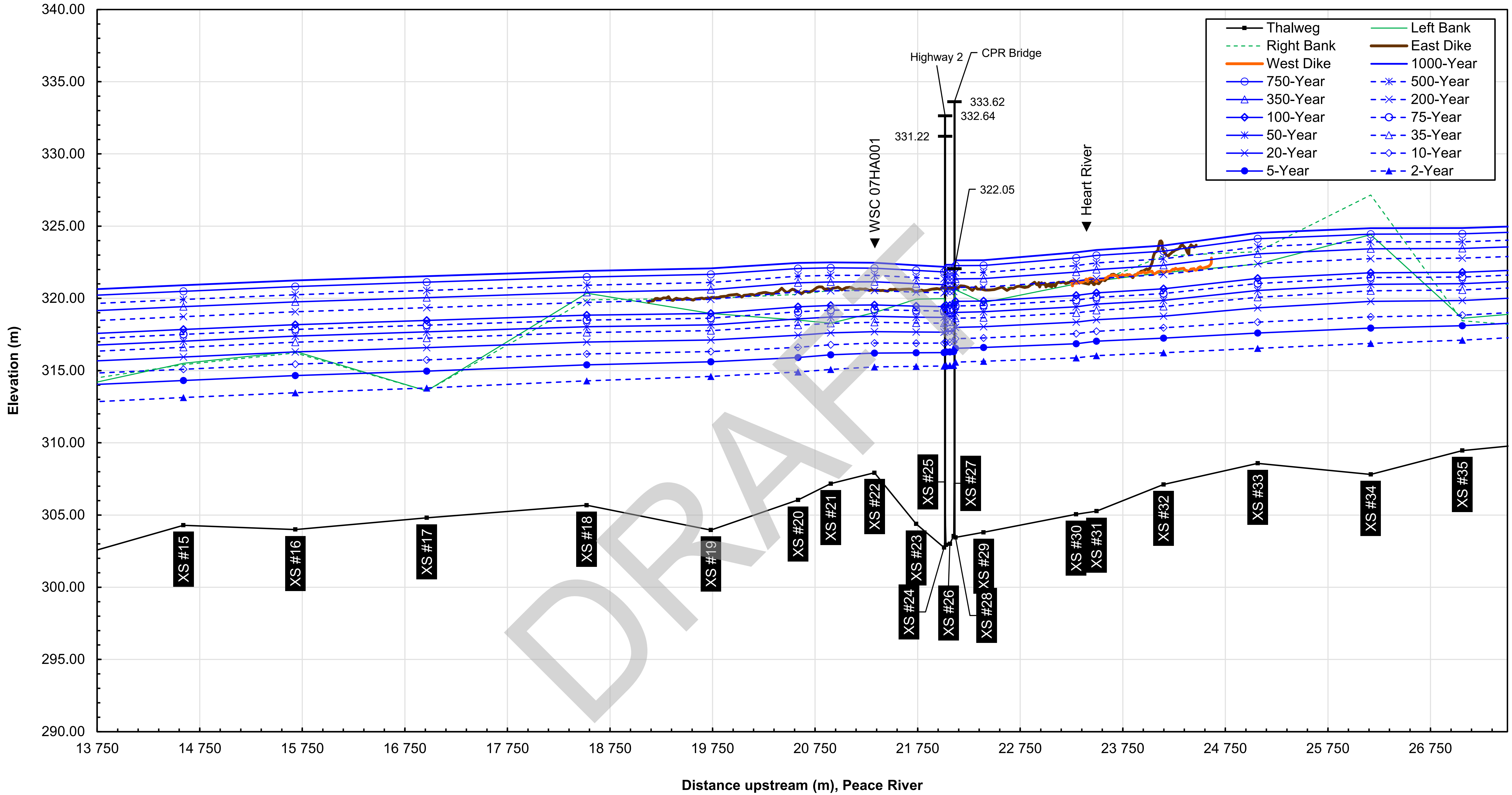
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **PEACE RIVER FLOOD FREQUENCY PROFILES (SHEET 1 OF 4)**		
1001119	23 JUN 2017	**FIGURE 13A**



ALBERTA ENVIRONMENT AND PARKS

PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

PEACE RIVER FLOOD FREQUENCY PROFILES (SHEET 2 OF 4)

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1001119	23 JUN 2017	**FIGURE 13B**

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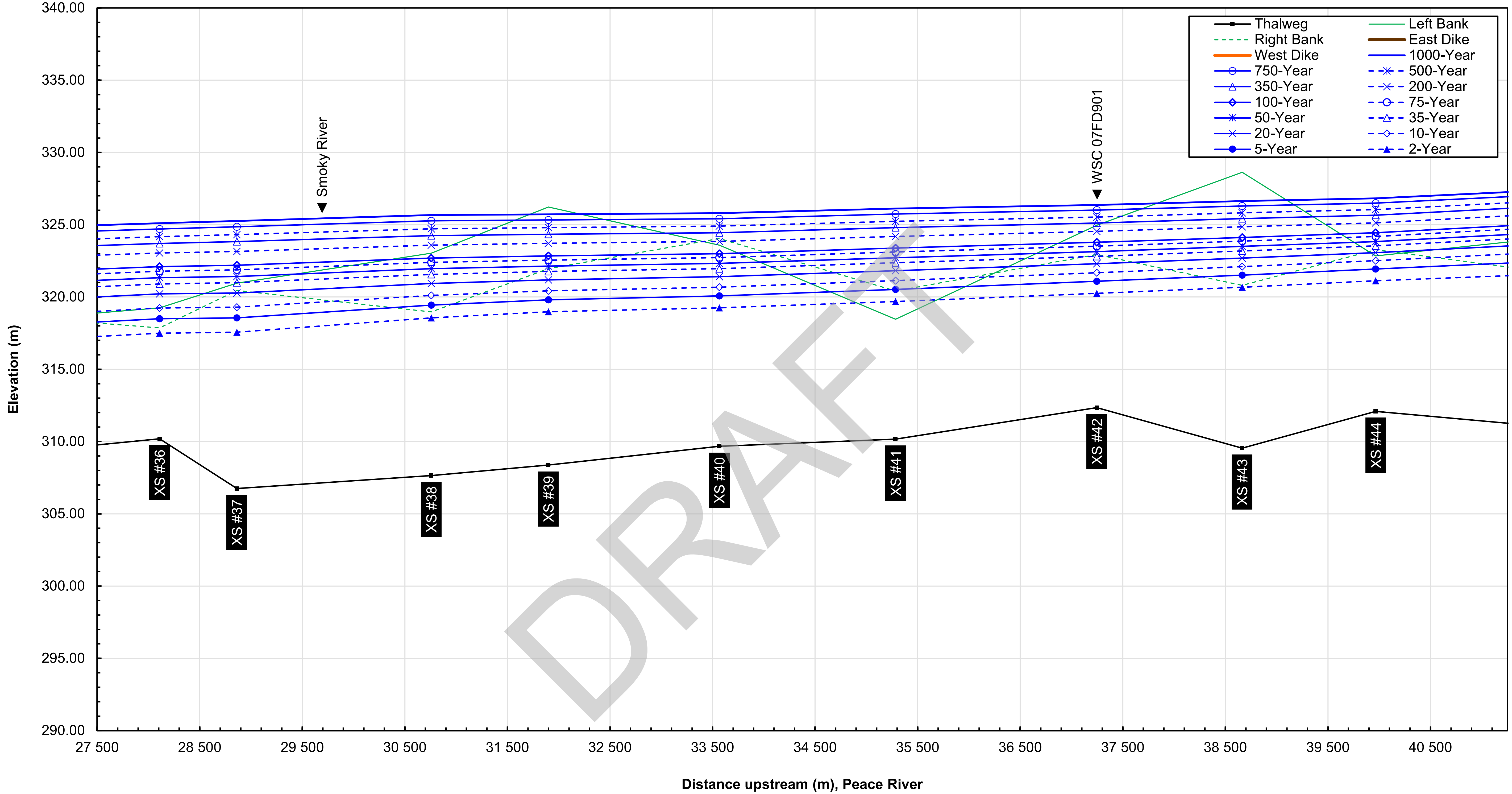

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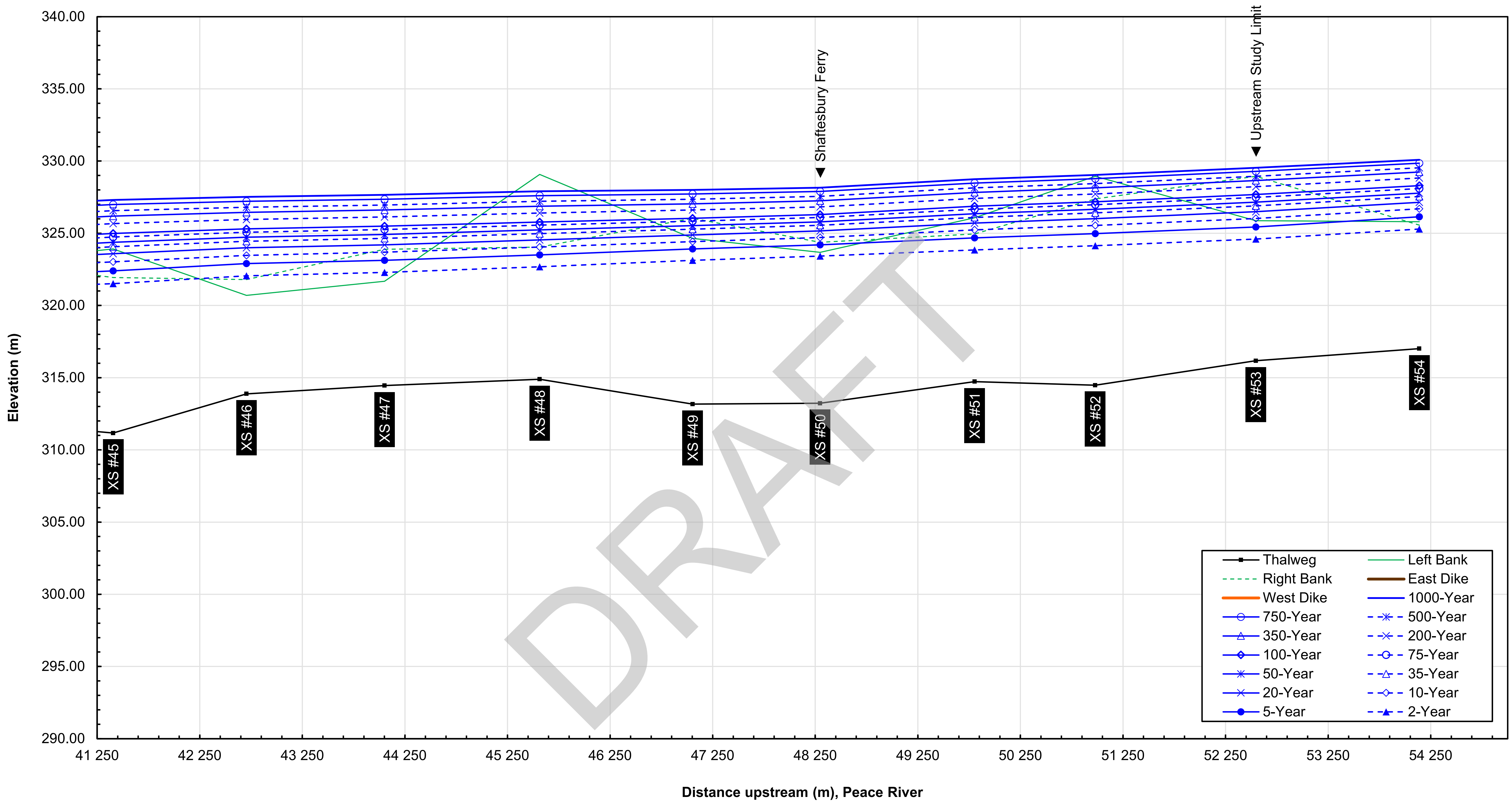
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **PEACE RIVER FLOOD FREQUENCY PROFILES (SHEET 3 OF 4)**		
1001119	23 JUN 2017	**FIGURE 13C**



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PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

PEACE RIVER FLOOD FREQUENCY PROFILES (SHEET 4 OF 4)

1001119	23 JUN 2017	**FIGURE 13D**

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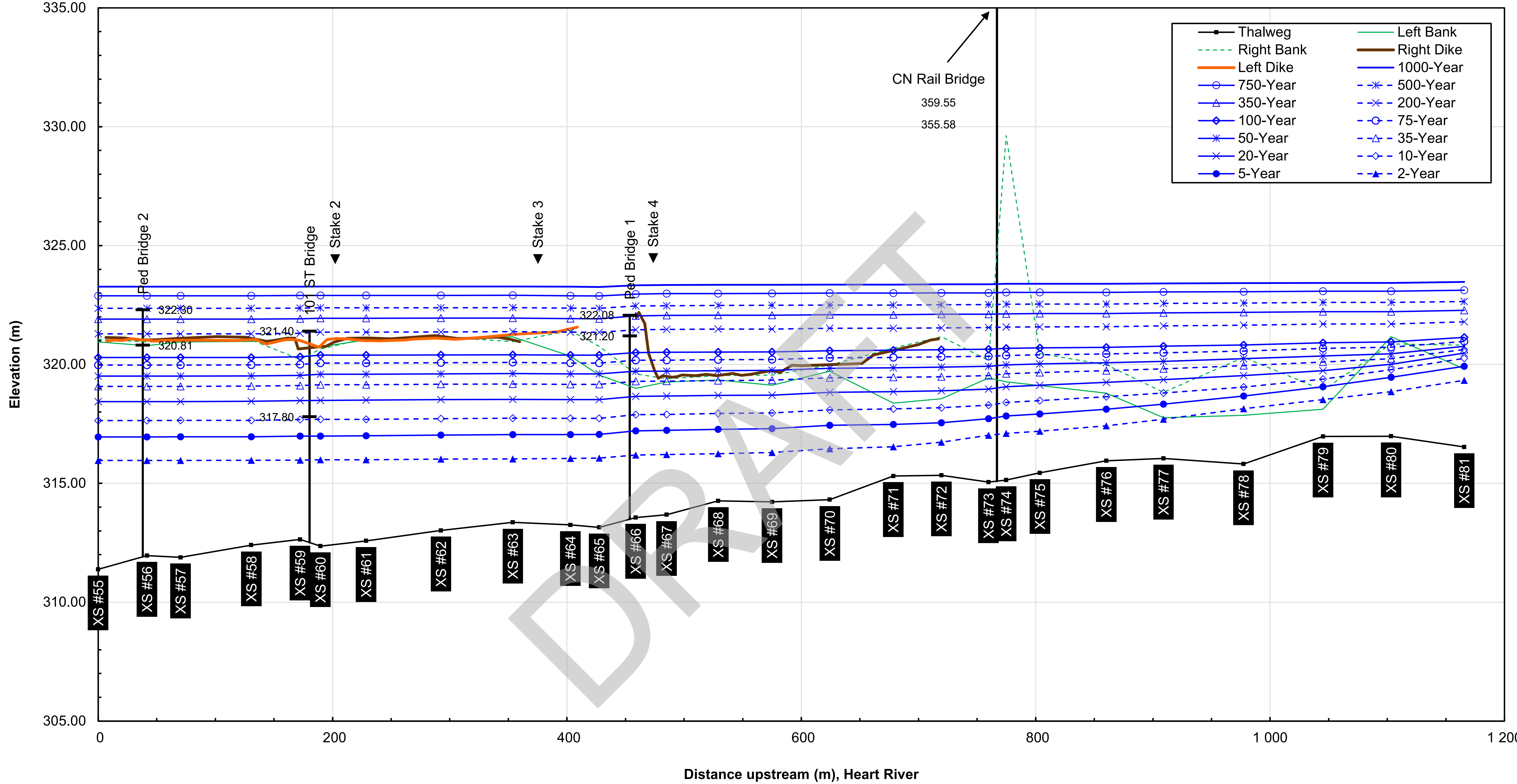
Classification: Public



ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HEART RIVER FLOOD FREQUENCY PROFILES**		
1001119	23 JUN 2017	**FIGURE 14**

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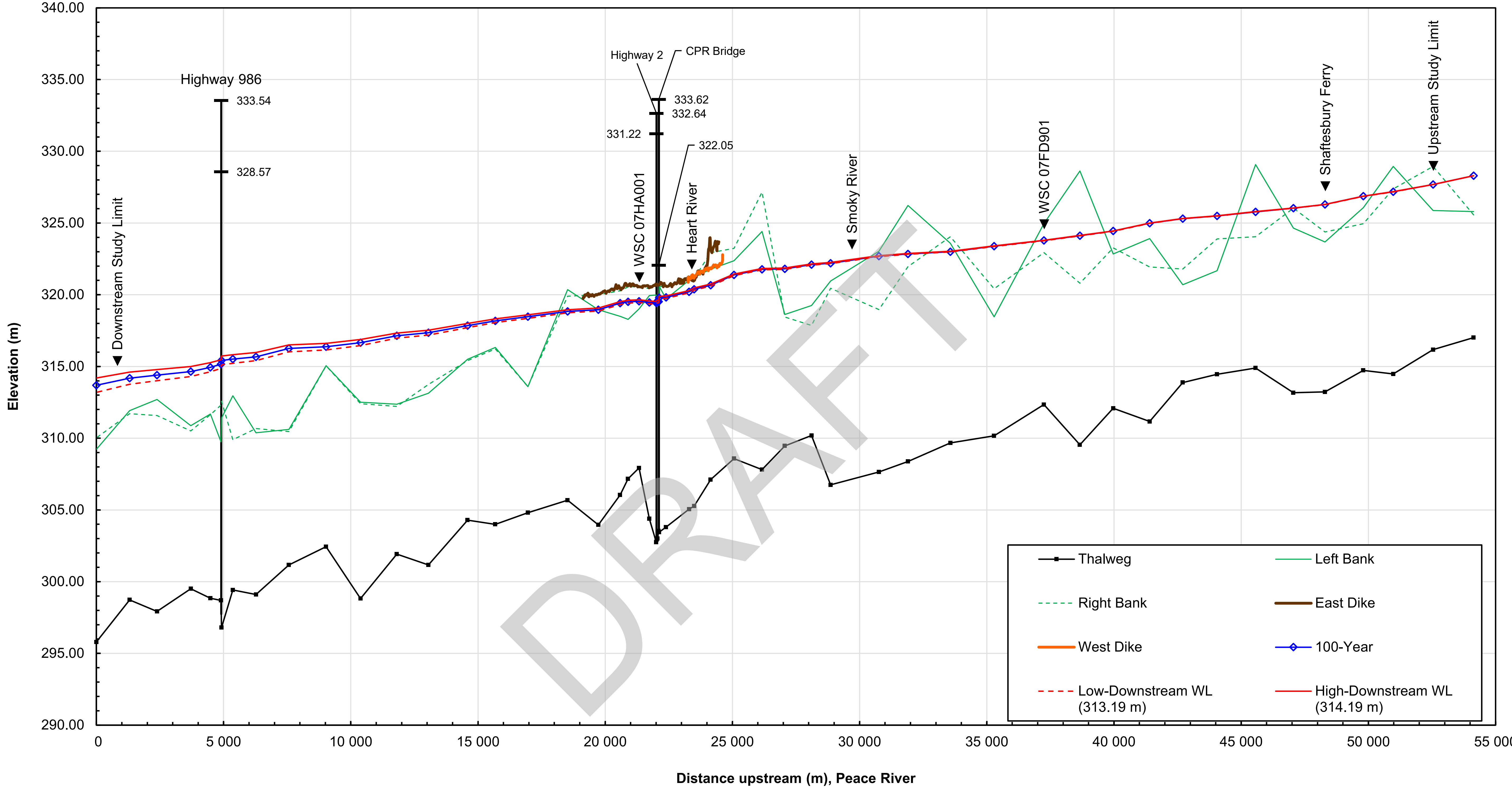

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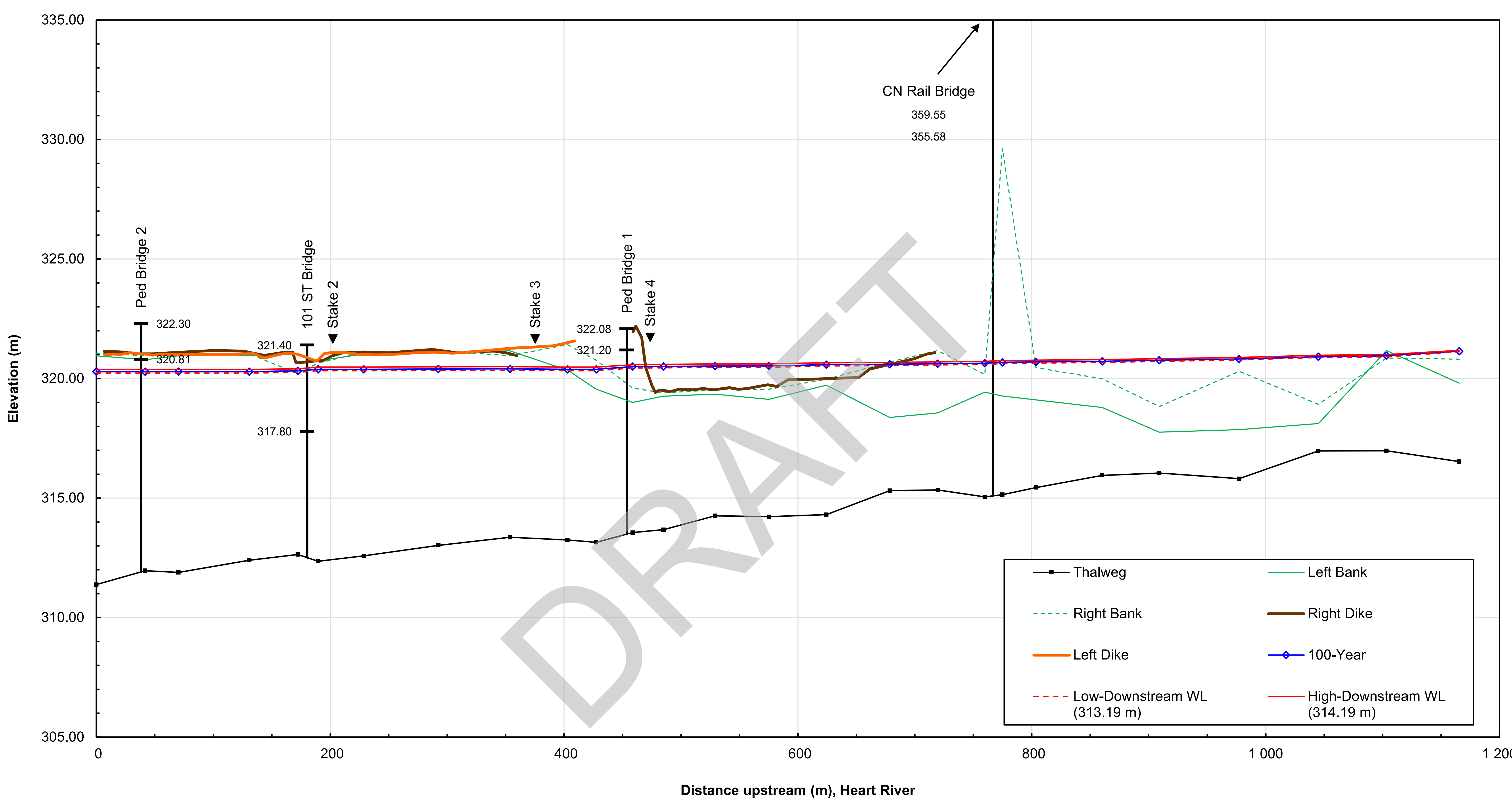
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO WATER LEVEL AT DOWNSTREAM BOUNDARY**		
1001119	23 JUN 2017	**FIGURE 15A**



Notes: 1. Downstream boundary for the Heart River is based on prescribed water levels for the Peace River computed for each sensitivity run.

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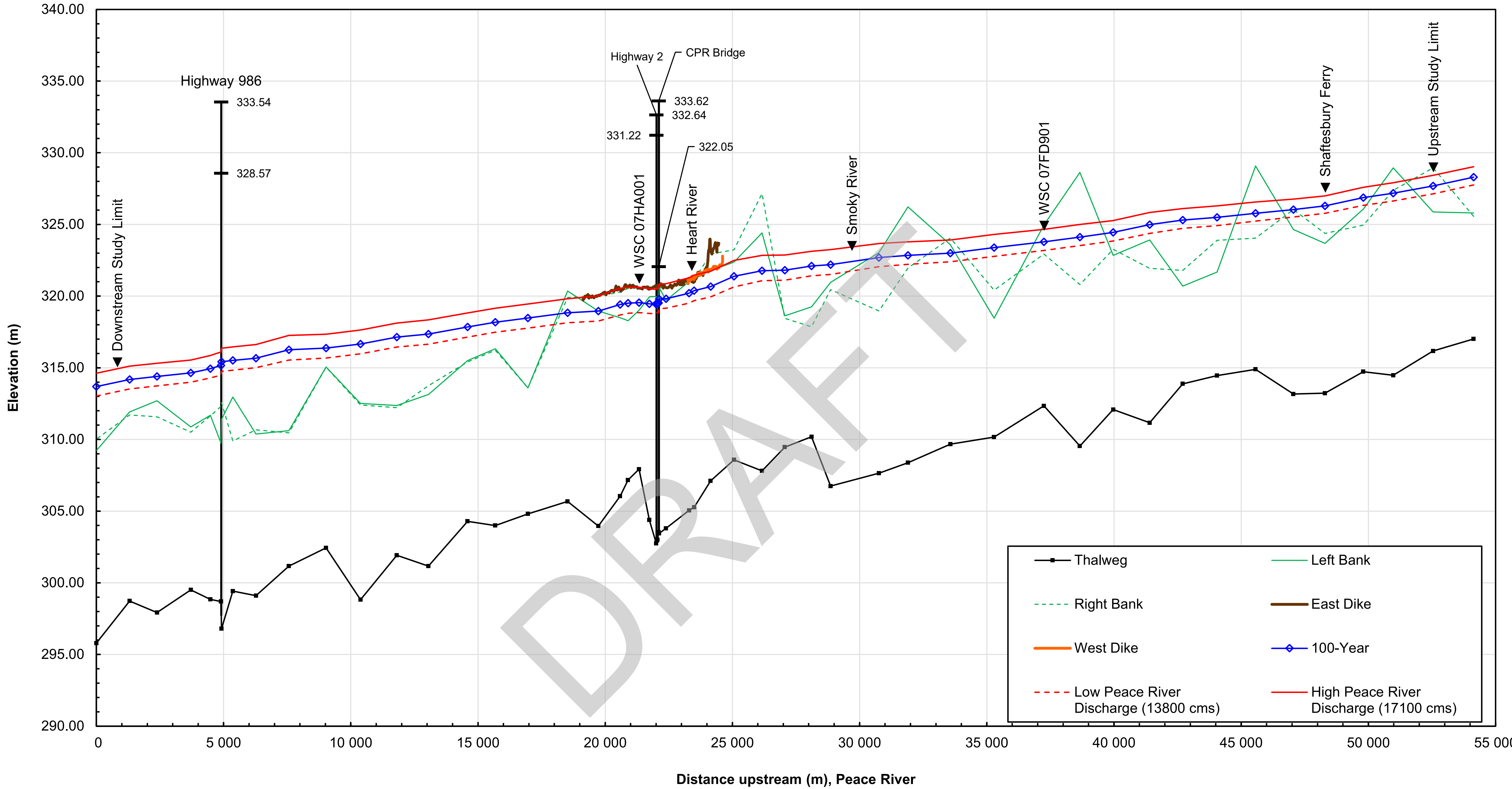
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO WATER LEVEL AT DOWNSTREAM BOUNDARY**		
1001119	23 JUN 2017	**FIGURE 15B**



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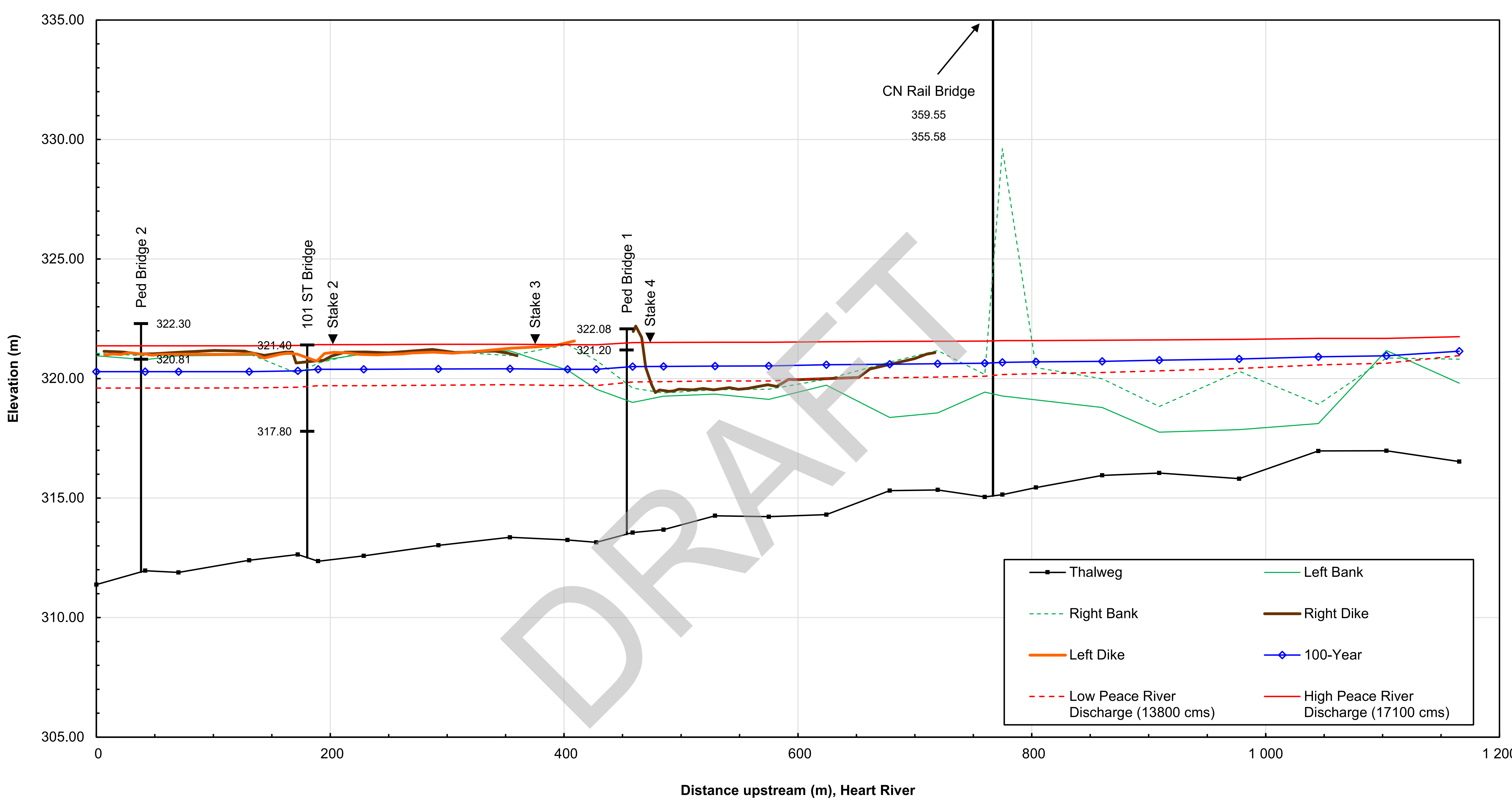
PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO DISCHARGE

1001119	23 JUN 2017	**FIGURE 16A**



Notes: 1. Downstream boundary for the Heart River is based on prescribed water levels for the Peace River computed for each sensitivity run.

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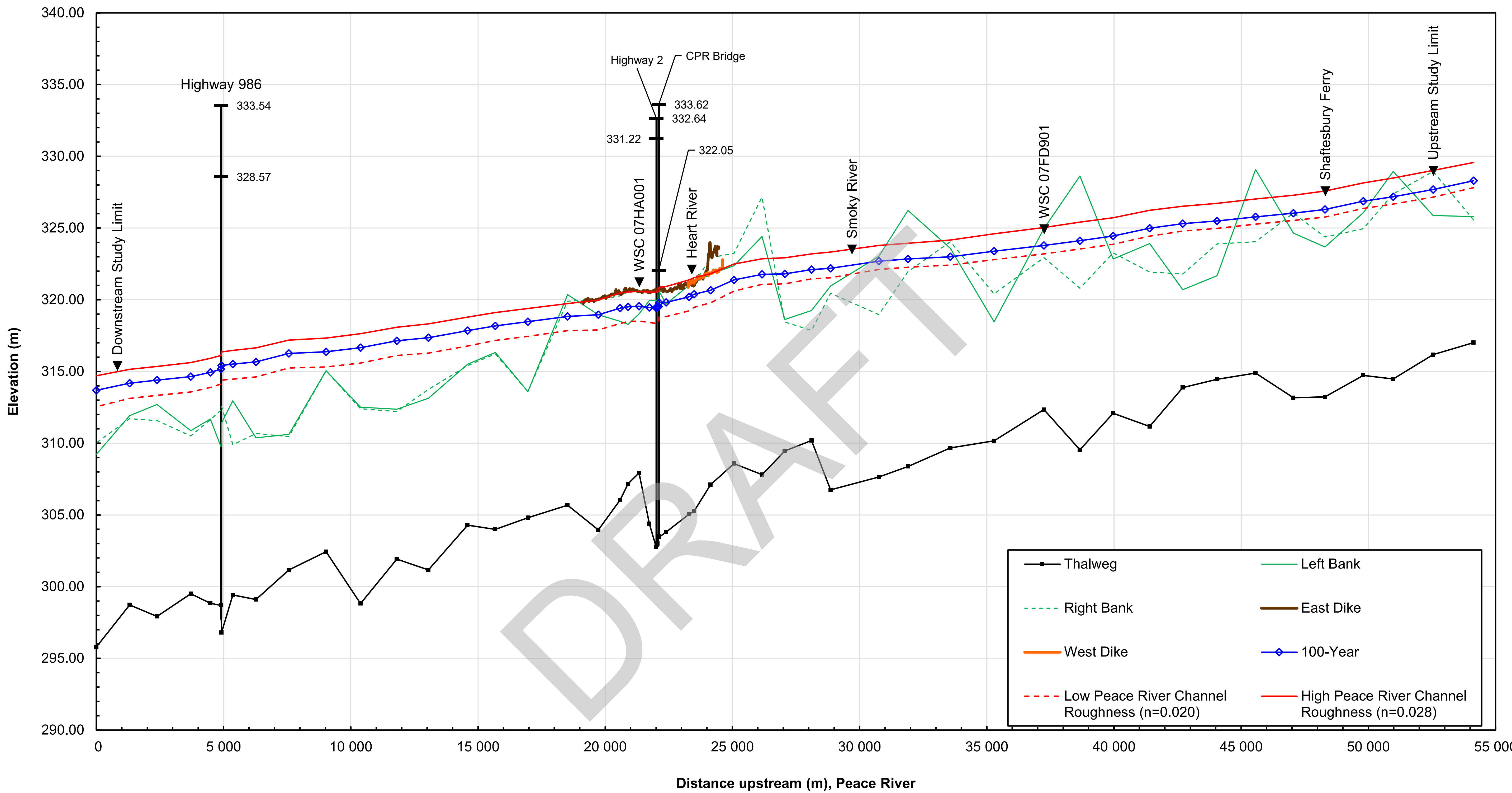
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO DISCHARGE**		
1001119	23 JUN 2017	**FIGURE 16B**



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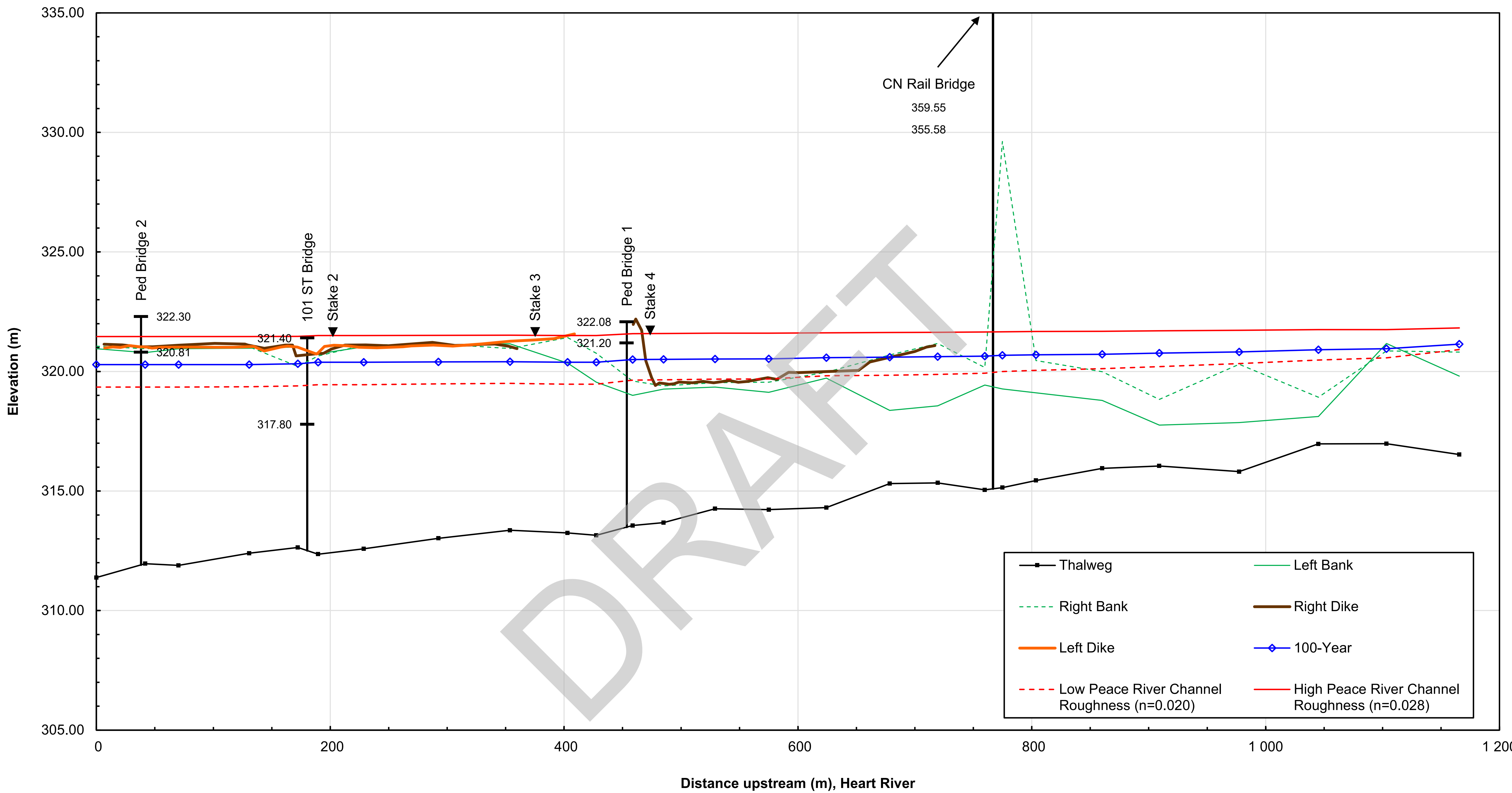
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO PEACE RIVER CHANNEL ROUGHNESS**		
1001119	23 JUN 2017	**FIGURE 17A**



Notes: 1. Downstream boundary for the Heart River is based on prescribed water levels for the Peace River computed for each sensitivity run.

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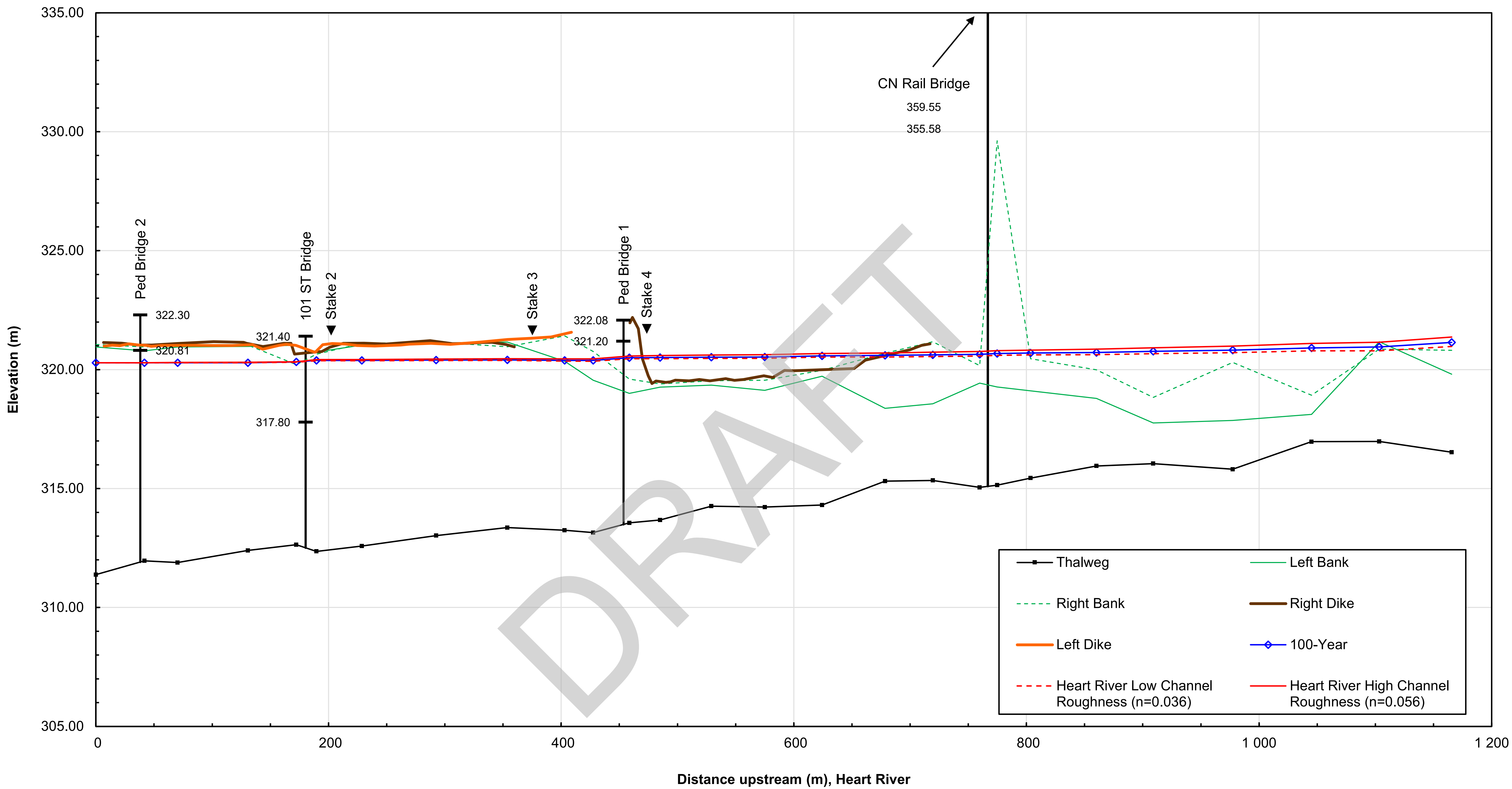
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO PEACE RIVER CHANNEL ROUGHNESS**		
1001119	23 JUN 2017	**FIGURE 17B**

Classification: Public



Notes: 1. Downstream boundary for the Heart River is based on prescribed water levels for the Peace River computed for each sensitivity run.

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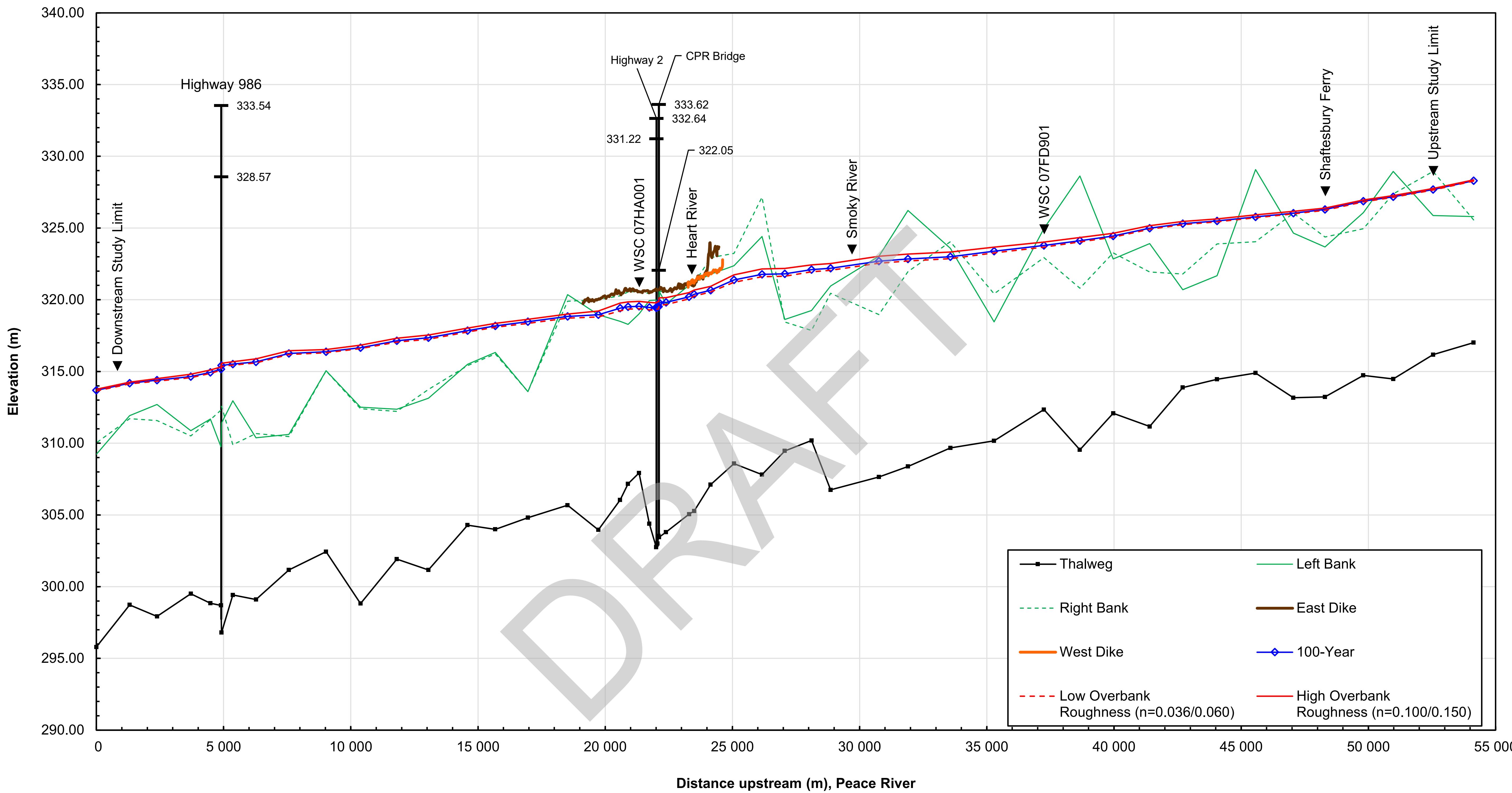
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO HEART RIVER CHANNEL ROUGHNESS**		
1001119	23 JUN 2017	**FIGURE 18**



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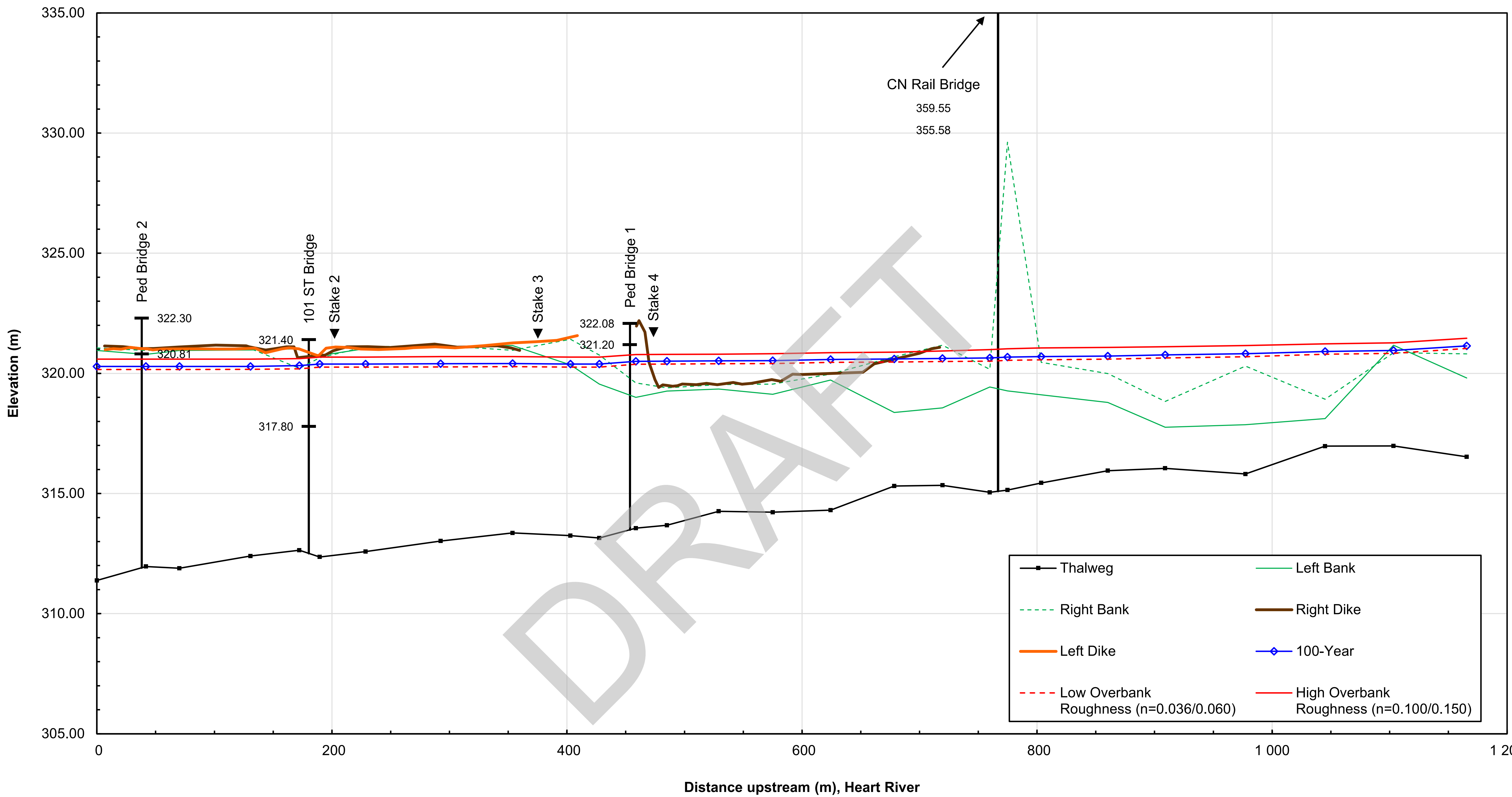
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO OVERBANK ROUGHNESS**		
1001119	23 JUN 2017	**FIGURE 19A**



Notes: 1. Downstream boundary for the Heart River is based on prescribed water levels for the Peace River computed for each sensitivity run.

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ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **COMPUTED 100-YEAR WATER SURFACE PROFILE SENSITIVITY TO OVERBANK ROUGHNESS**		
1001119	23 JUN 2017	**FIGURE 19B**

Classification: Public

Appendix A
Flood History Photo Documentation

Notes:

1. (Top left) Looking north on Main (100th) Street from the intersection of 100th Avenue. Image 68.037.
2. (Top right) Looking north up Main (100) Street from 99th Avenue towards the shops on the west side of the street. The welcome sign at the entrance of the town, Miller Electric, My Valet Cleaners, Star Cafe. Image 82.1216.004.
3. (Bottom left) Looking south on Main (100th) Street towards 102 Avenue from 101 Avenue. Image 2008.037.012.
4. (Bottom right) Looking east past the old fire hall (looking down 99th Avenue to the east). Image 72.484d.

[Images from Peace River Museum and Archives / Mackenzie Centre]

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PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

HISTORICAL OPEN WATER FLOODING
1935 – PAT'S CREEK

1001119	31 OCT 2016	**FIGURE A-1**

Classification: Public

Notes: Images from:

(Left) Logan Clow/Peace River Record-Gazette/QMI Agency. (8 April 2014). Peace River flooding downtown forces evacuation. Edmonton Sun. Accessed 26 July 2016 from: http://www.edmontonsun.com/2014/04/08/peace-river-flooding-downtown-forces-evacuation

(Right) Government of Alberta.

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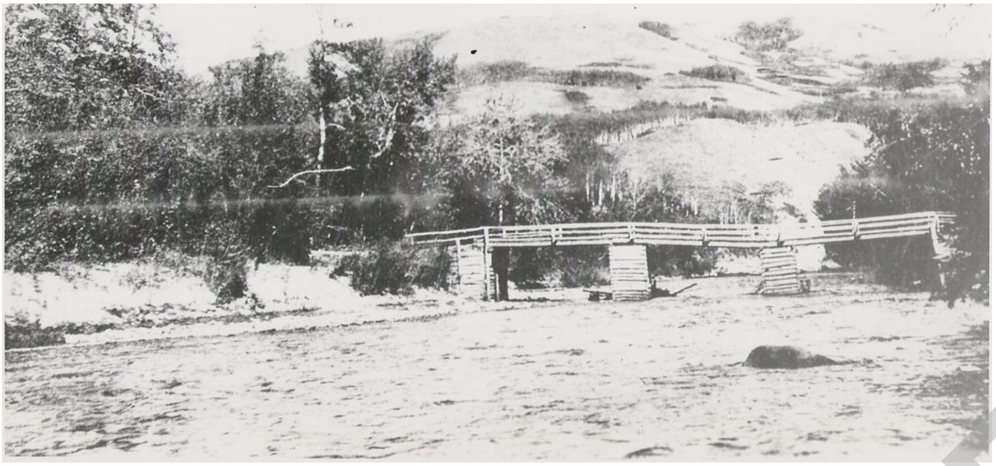
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HISTORICAL OPEN WATER FLOODING 27 JUNE 2013 – PAT'S CREEK**		
1001119	31 OCT 2016	**FIGURE A-2**



Notes:

1. (Top left) The first bridge on the Heart River in Peace River Crossing, circa 1910-1912. Image 79.1068.058.
2. (Top right) The Heart River bridge shortly before its collapse during the 1914 flood. Image 73.558.c.
3. (Bottom left) The Heart River overflowing its banks in 1914. Image AR89.36.10.
4. (Bottom right) The Revillon Freres buildings at Peace River Crossing during the 1914 flood. Image 77.765.17.

[Images from Peace River Museum and Archives / Mackenzie Centre]

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PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

HISTORICAL OPEN WATER FLOODING
1914 – HEART RIVER

1001119	31 OCT 2016	**FIGURE A-3**

Classification: Public

Notes: 1. The Heart River in possible flood in 1923. Photo taken in Northern Sunrise County. Image 79.1075.019

[Image from Peace River Museum and Archives / Mackenzie Centre]

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ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HISTORICAL OPEN WATER FLOODING** **POSSIBLE FLOOD 1923 – HEART RIVER**		
1001119	31 OCT 2016	**FIGURE A-4**

Notes: 1. In 1914 a severe flood created huge problems for the growing community of Peace River Crossing. In this view one is looking north along the Peace River and to the right are the buildings of the Hudson's Bay Company. Unfortunately this was the first of several floods to impact the area over the next century. Image 81.1152.22.

[Images from Peace River Museum and Archives / Mackenzie Centre]

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ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HISTORICAL OPEN WATER FLOODING** **1914 – PEACE RIVER**		
1001119	31 OCT 2016	**FIGURE A-5**

Classification: Public

Notes:

1. (Top left) Photo taken from the east bank of the Peace River. Image 2008.037.019.
2. (Bottom left) Photo of the east bank of the Peace River. High water levels suggest this was before the flood. Image 2008.037.020.
3. (Right) Trees being flooded by the Peace River. In the background the train bridge can barely be seen. Image 2008.037.17.

[Images from Peace River Museum and Archives / Mackenzie Centre]

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PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

HISTORICAL OPEN WATER FLOODING
1935 – PEACE RIVER

1001119	31 OCT 2016	**FIGURE A-6**

Heart River, filled to its capacity, was about to spill over the dykes and down Main Street

Bridge to 12-Foot Davis Ball Park and 101st Street Bridge, both over the Heart River, hold their own.

Notes: 1. Flooding on the Heart River due to backwater effects from the Peace River.

[Images from Nelson, Dave (1972). Flood Peace River 1972. Valley Printers. Peace River Museum and Archives / Mackenzie Centre Item Number FC 3693.]

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ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED OPEN WATER FLOODING 14 JUNE 1972 – HEART RIVER DUE TO PEACE RIVER BACKWATER EFFECTS**		
1001119	31 OCT 2016	**FIGURE A-7**

Notes:

1. (Top) Looking downstream towards the Heart River bridge in Peace River.
2. (Bottom right) Looking upstream from town side, note slumping on banks.
3. (Bottom left). South abutment on upstream side. Note high water mark on concrete.

[Image Source: Alberta Transportation and Utilties Bridge Engineering Branch, File 2010.]

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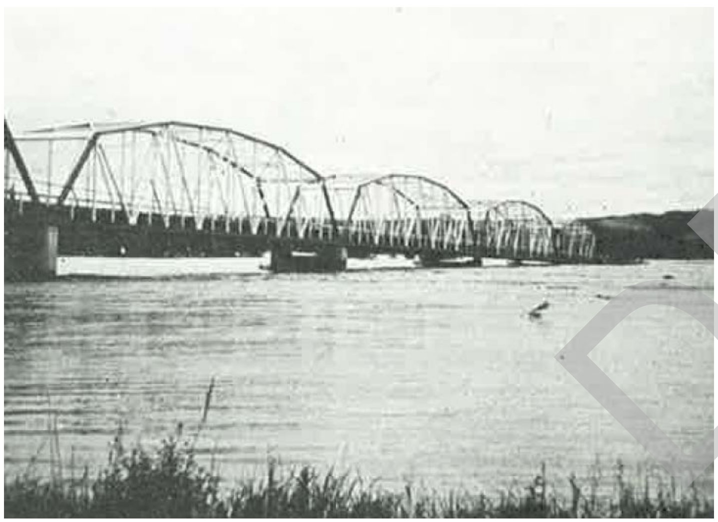
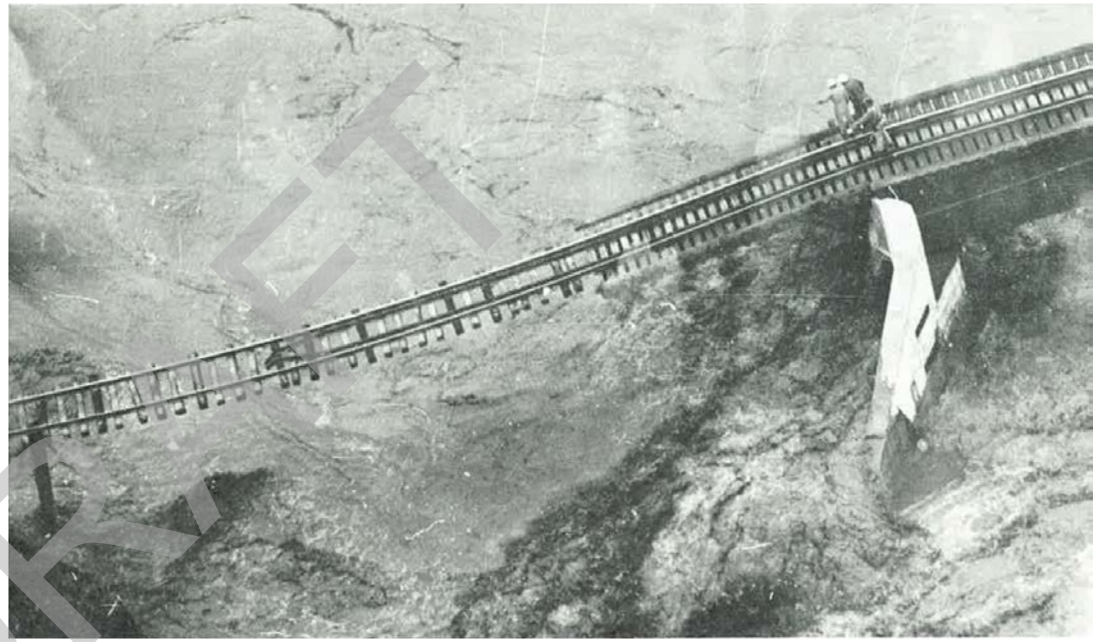
ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED OPEN WATER FLOODING 14 JUNE 1990 – HEART RIVER DUE TO PEACE RIVER BACKWATER EFFECTS**		
1001119	31 OCT 2016	**FIGURE A-8**





Notes:

1. (Top left) Smoky River at Watino, taken from south end of bridge on Highway 49 and looking downstream. Gauge height at time of photograph=32.0 ft.
2. (Bottom left) Smoky River at Watino taken from left bank, downstream of bridge on Highway 49. Gauge height at time of photograph=32.0 ft.

[Photos from Warner, L.A. and Thompson, W.C. (1974).]

3. (Right) Northern Alberta Railway bridge at Watino yields to the onslaught of water from the Smoky River.

[Photo taken by Peace River Record-Gazette staffer Dave Nelson]

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED OPEN WATER FLOODING** **14 JUNE 1972 – SMOKY RIVER**		
1001119	31 OCT 2016	**FIGURE A-9**

Notes:

1. (Top left) Joe Green home, West Peace River, submerged under four feet of water.
2. (Top right) Street sign at the intersection of 91 Street and 107? Avenue.
3. (Bottom left) Ernie Skip commandeers a boat down 98th Street.
4. (Bottom right) The raging Peace River pulled trees out of the banks by the roots.

[Images from Nelson, Dave (1972). Flood Peace River 1972. Valley Printers. Peace River Museum and Archives / Mackenzie Centre Item Number FC 3693.]

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PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

RECORDED OPEN WATER FLOODING
14 JUNE 1972 – PEACE RIVER

1001119	31 OCT 2016	**FIGURE A-10**

Notes:

1. (Top left) 14 June, minor slump on left bank.
2. (Top right) 14 June, looking upstream. Note drift on railroad piers and large wake behind piers.
3. (Bottom left) 13 June, 0.8 m below peak high water. Taken at 5:00 pm.

[Images from Alberta Transportation, Bridge File 75946-1990, Highway 2.]

4. (Bottom right) 13 June, Highway 986 Bridge construction site.

[Image from Alberta Transportation, Bridge File 81239-1990, NE of Weberville.]

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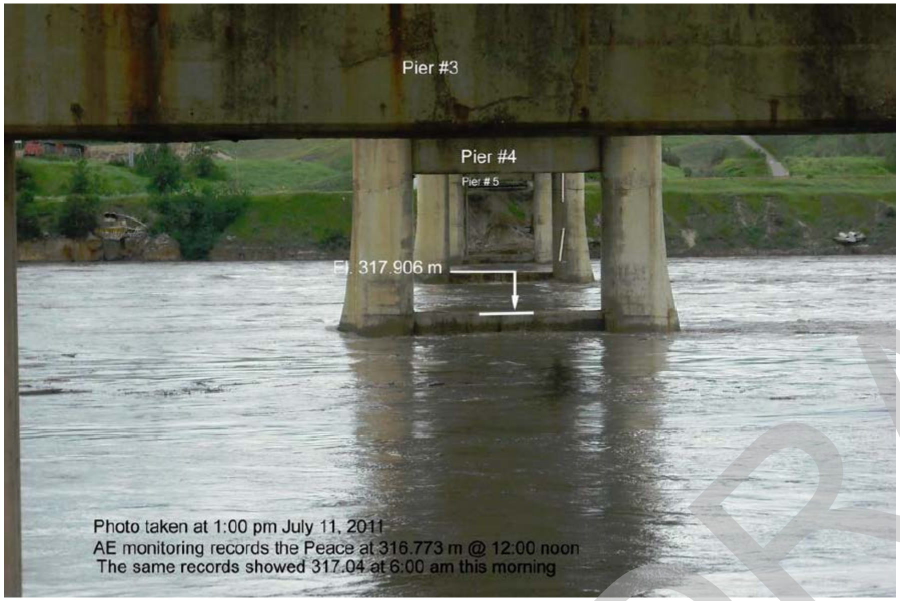
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED OPEN WATER FLOODING 13-14 JUNE 1990 – PEACE RIVER**		
1001119	31 OCT 2016	**FIGURE A-11**



Notes:
1. (Left) Photo taken at 1:00 pm on 11 July.
2. (Right) Photo taken at 1:00 pm on 11 July.

[Images from Alberta Transportation, Bridge File 75946-2011, Highway 2 Bridge.]

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED OPEN WATER FLOODING JULY 2011 – PEACE RIVER**		
1001119	31 OCT 2016	**FIGURE A-12**

Notes: 1. Looking south showing 102 Avenue (Rotten Row) flooded in 1914. Image 87.1521.46.

[Image from Peace River Museum and Archives / Mackenzie Centre]

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ALBERTA ENVIRONMENT AND PARKS		
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HISTORICAL ICE AFFECTED FLOODING APRIL 1914 – PAT'S CREEK**		
1001119	31 OCT 2016	**FIGURE A-13**

Classification: Public

Notes:
1. (Left) April 17, 1958. Looking south down Main (100th) Street – where the side of the Fire Hall is located is 99th Avenue. Image 83.1308.033.
2. (Right) Pat's Creek water rushing up against a bridge in Peace River, Alberta. Possibly the bridge where Main Street crossed Pat's Creek. Looking East from the edge of 100th Avenue. Image 87.1536.047.

[Images from Peace River Museum and Archives / Mackenzie Centre]

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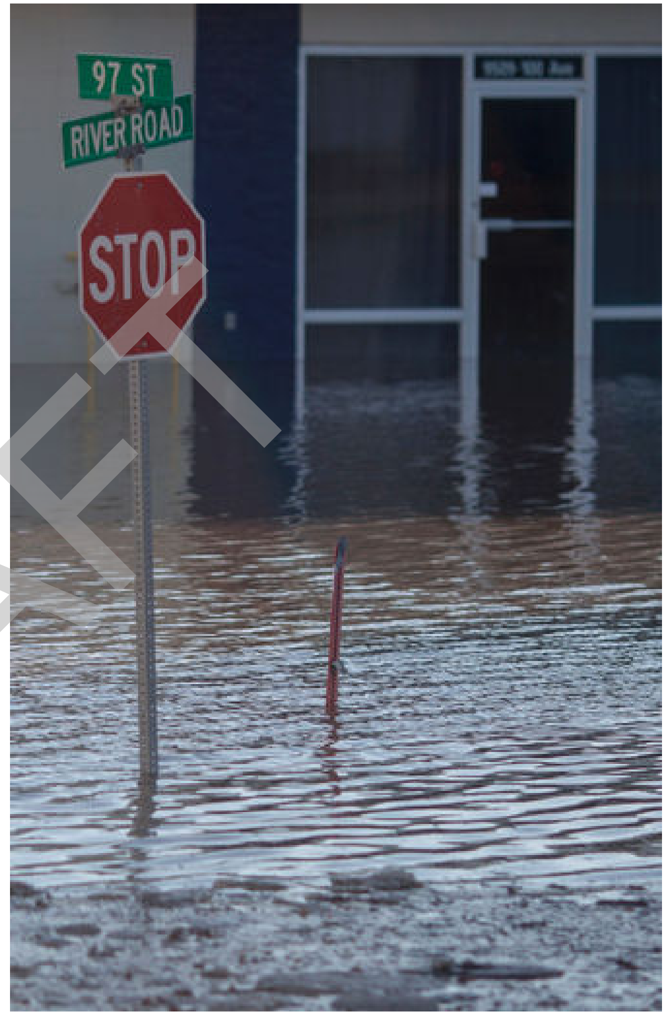
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HISTORICAL ICE AFFECTED FLOODING 17 APRIL 1958 – PAT'S CREEK**		
1001119	31 OCT 2016	**FIGURE A-14**



Notes: Images from: Adam Dietrich/Record-Gazette/QMI Agency. (9 April 2014) Daily Herald Tribune. Accessed 26 July 2016 from http://www.dailyheraldtribune.com/2014/04/09/downtown-peace-river-floods

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **HISTORICAL ICE AFFECTED FLOODING** **8 APRIL 2014 – PAT'S CREEK**		
1001119	31 OCT 2016	**FIGURE A-15**


Notes:
1. (Left) Looking upstream. River ice intact.
2. (Right) Looking downstream. Water had overtopped berms. Crews pumping flood water back into river.

[Images from Alberta Transportation, Bridge File 2010-1992, Heart River Bridge.]

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED ICE AFFECTED FLOODING 29 FEB 1992 – HEART RIVER DUE TO PEACE RIVER BACKWATER EFFECTS**		
1001119	31 OCT 2016	**FIGURE A-16**

Notes: 1. 18 April flooding on the Heart River.

[Images from Town of Peace River.]

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED ICE AFFECTED FLOODING 18 APRIL 1997 – HEART RIVER DUE TO PEACE RIVER BACKWATER EFFECTS**		
1001119	31 OCT 2016	**FIGURE A-17**

Notes: 1. (Left) Flooding in Twelve Foot Davis Baseball Park.
2. (Right) Ice jam in the Heart River at the Town of Peace River.

[Image Source: Alberta Environment (2005). Peace River Ice Observations 2004 – 2005.]

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED ICE AFFECTED FLOODING** **9 MARCH 2005 – HEART RIVER**

1001119	31 OCT 2016	**FIGURE A-18**

Notes: 1. (Left) March 23, open channel through where the ice previously was on the Heart River in the Town of Peace River at Twelve Foot Davis Baseball Diamond.
2. (Right) March 28, view of the Heart River as it flows through Peace River from right to left.

[Images from Alberta Environment (2015). Peace River Ice Observations 2014 – 2015.]

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PEACE RIVER HAZARD STUDY
HYDRAULIC MODEL CREATION AND CALIBRATION

RECORDED ICE AFFECTED FLOODING
15 MARCH 2015 – HEART RIVER

1001119	31 OCT 2016	**FIGURE A-19**

Notes:

1. (Top left) 28 Feb 9:00 am, Railroad bridge in Peace River.
2. (Top right) 28 Feb 9:00 am, Peace River bridge.
3. (Bottom left) 29 Feb, Looking northeast at north residential area subject to worst flooding.
4. (Bottom right) 28 Feb 9:00 am, Ice level in Town of Peace River

[Images from Alberta Transportation, Bridge File 75946-1992, Highway 2 Bridge.]

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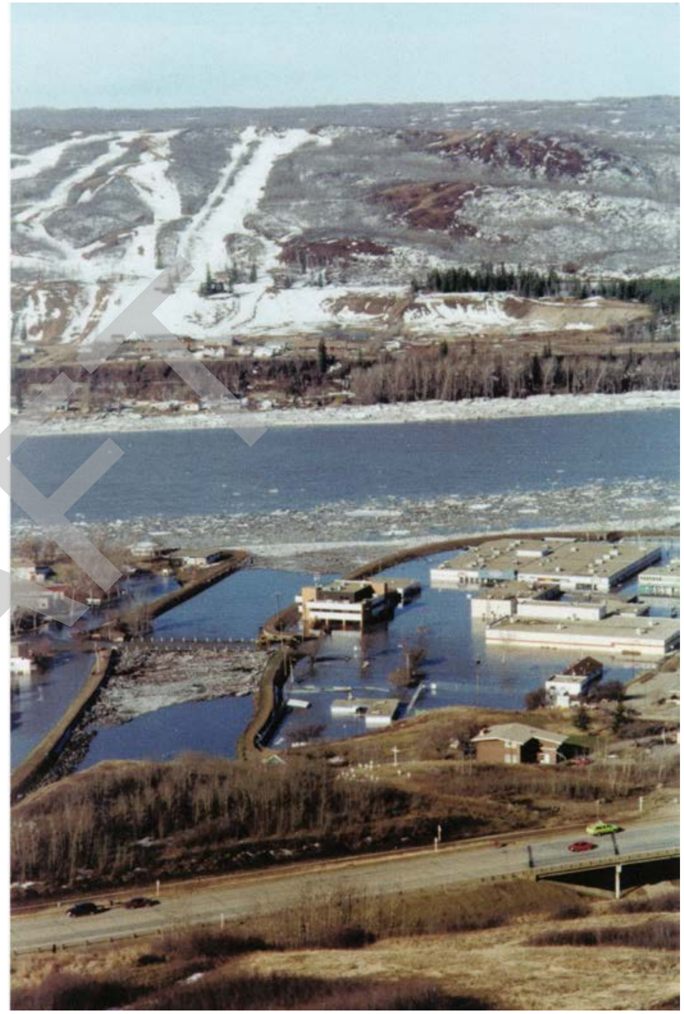
PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED ICE AFFECTED FLOODING** **27 FEB – 2 MAR 1992 – PEACE RIVER**		
1001119	31 OCT 2016	**FIGURE A-20**



Notes:

1. (Left) Flooding in Peace River on 19 April. *[Images from Town of Peace River]*
2. (Right) 1997 Flood *[Image from Peace River Museum and Archives / Mackenzie Centre]*

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PEACE RIVER HAZARD STUDY HYDRAULIC MODEL CREATION AND CALIBRATION **RECORDED ICE AFFECTED FLOODING** **18-23 APR 1997 – PEACE RIVER**		
1001119	31 OCT 2016	**FIGURE A-21**