Robb Flood Study

Main Report

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- Hammad Javid — Project Manager
- Massoud Shafieifar — River Forecast Engineer, Project Advisor
- Michael Brayall — River Hydraulics and Ice Engineer, Project Advisor

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EXECUTIVE SUMMARY

In September 2024, Alberta Environment and Protected Areas (EPA) enlisted the services of Northwest Hydraulic Consultants Ltd. (NHC) to complete a flood study for areas along 10 km of Embarras River and 3 km of Bryan Creek through Yellowhead County, including the Hamlet of Robb. This study was conducted under the Flood Hazard Identification Program (FHIP) with the goals of enhancing public safety and mitigating potential flood damages in the province.

The Robb Flood Study is comprised of five major project components: 1) survey and base data collection; 2) open water hydrology assessment; 3) open water hydraulic modelling; 4) open water flood inundation mapping; and 5) design flood hazard mapping. This report summarizes the work of all five components, and together they include the following details:

- descriptions of survey procedures and methodology
- documentation of the collected survey and base data
- summary of flood history
- open water flood frequency flow estimations
- construction, calibration, and validation of the hydraulic model
- computation of flood frequency water levels
- a model sensitivity analysis
- associated inundation mapping
- computation of design flood profiles
- floodway criteria and hazard mapping

The survey program for Robb Flood Study was completed in October 2024. The objective of the survey program was to survey river cross sections and hydraulic structures along the Embarras River and Bryan Creek study reach to support the development of a one-dimensional (1D) hydraulic model. In addition to this, data such as Digital Terrain Model (DTM), aerial imagery, and other mapping features were gathered for model development and flood mapping efforts. The model calibration and validation data, including highwater marks (HWMs), were collected for the flood in June 2023. In addition, NHC measured discharges and surveyed the corresponding water levels for the Embarras River and Bryan Creek study reaches as part of their October 2024 survey program.

Open water flood frequency estimates were completed at three locations within the study area: two of them were along the Embarras River study reach and one at Bryan Creek study reach. Flood magnitudes for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year events were estimated at these locations based on the regional analysis. These flood frequency estimates were later compared with those from a previous study conducted by Alberta Environment (AENV) in 1984 and with another study conducted by Associated

Engineering (Associated) in 2001. In general, the current study provides lower flood peak estimates from previous studies. Notably, there is no existing provincial flood hazard mapping for the Hamlet of Robb, and none of these prior flood frequency estimates were linked to detailed flood mapping based on provincial guidelines and standards. In addition, the current estimates are considered more accurate due to the use of longer and more recent data series and also due to the selection of homogeneous gauges in the regional analysis.

The open water hydraulic modelling task involved the creation, calibration, and validation of a hydraulic model, computation of flood levels, and conducting a model sensitivity analysis. A 1D hydraulic model was developed based on the survey data and DTM. The model was calibrated using HWMs collected during the June 2023 flood at Embarras River, with channel Manning's roughness selected as the primary calibration parameter. The model was later validated using the 2024 NHC measured discharges and corresponding surveyed water levels. The calibrated model was then used to generate water surface profiles for 13 flood scenarios, ranging from the 2-year to the 1000-year open water flood events. Finally, a sensitivity analysis was performed by varying inflow discharges, downstream boundary conditions, channel and overbank roughness values. The results indicated that the model was most sensitive to changes in inflow discharge and channel roughness, with discharge having a notably greater impact due to the limited conveyance capacity of the Township Road 492A culvert. While discharge magnitude directly affects water levels and inundation widths, the effect is amplified when flow is constrained by limited culvert capacity. However, the increase in water levels and inundation widths were observed only in the backwater area influenced by the culvert's constriction.

The computed flood levels were used to determine the extent of inundation for each of the respective flood scenarios and are presented as a set of flood inundation maps for each scenario (the flood inundation map library). This library is intended primarily for stakeholders to use in emergency response planning and preparation. The maps show that no significant impacts are expected in Upper Robb, while several houses in Lower Robb could be affected by a 20-year or larger flood, and buildings and cabins in the Mile 34 area may be impacted during 200-year and larger flood events. Within the study area, there are nine hydraulic structures: five bridges and four culverts. Of the bridges, only the private crossing bridge at Mile 34 could be affected during the 350-year and larger floods. Among the culverts, the Township Road 492A and Valley Road crossings are likely to be overtopped during the 350-year and larger flood events. The Township Road 492A culvert, in particular, was identified as significantly undersized for larger floods and is expected to be submerged at the 10-year and higher flood levels.

The design flood hazard map (a key deliverable for this flood study) depicts the floodway and flood fringe (including high hazard flood fringe) areas for the open water design flood. The supporting rationale for the flood hazard map is depicted on the open water floodway criteria map. The methods used to develop the flood hazard map follow the provincial Flood Hazard Identification Program guidelines, incorporating technical changes implemented in 2021 regarding how floodways are mapped in Alberta. The floodway criteria and flood hazard maps show no notable overbank areas within the floodway.

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ABBREVIATIONS

Acronym / Abbreviation	Definition
1D	One-Dimensional
2D	Two-Dimensional
3TM	Three-Degree Transverse Mercator
AFETUW	Alberta Flow Estimation Tool for Ungauged Watershed
ASCM	Alberta Survey Control Marker
AT	Alberta Transportation
ATS	Alberta Township System
BF	Bridge File
CGVD28	Canadian Geodetic Vertical Datum of 1928
CSRS	Canadian Spatial Reference System
DTM	Digital Terrain Model
EGBC	Engineers and Geoscientists British Columbia
EPA	Alberta Environment and Protected Areas
FHIP	Flood Hazard Identification Program
GNSS	Global Navigation Satellite Systems
HEC-RAS	Hydrologic Engineering Center River Analysis System
HWM	Highwater Mark
NAD83	North American Datum 1983
NHC	Northwest Hydraulic Consultants Ltd.
P3	Pearson type III
PFRA	Prairie Farm Rehabilitation Administration
PPP	Precise Point Positioning
PXS	Planned Cross Section
RTK	Real-Time Kinematic
TEC	Alberta Transportation and Economic Corridors
TIN	Triangular Irregular Network

Acronym / Abbreviation	Definition
TOB	Top of Bank
WSC	Water Survey of Canada
WSE	Water Surface Elevation

SYMBOLS AND UNITS OF MEASURE

Symbol / Unit of Measure	Definition
°	degree
±	plus or minus
%	percent
cm	centimetre
km	kilometre
km^2	square kilometre
m	metre
m^3	cubic metre
m/s	metres per second
m^3/s	cubic metres per second
m/m	metres per metre

1 INTRODUCTION

This section provides comprehensive insights into the background of the Robb Flood Study, outlines its specific objectives, and provides a detailed description of the study area and its reaches.

1.1 Study Background

In September 2024, Alberta Environment and Protected Areas (EPA) retained Northwest Hydraulic Consultants Ltd. (NHC) to complete a flood study for areas along approximately 10 km of Embarras River and 3 km of Bryan Creek through Yellowhead County, including the Hamlet of Robb. This study is part of Alberta's Flood Hazard Identification Program, which is intended to enhance public safety and reduce future flood damages in the province. Results from this study are also intended to inform local land use planning decisions, flood mitigation projects, and emergency response planning.

The Robb Flood Study is comprised of five major components: 1) survey and base data collection; 2) open water hydrology assessment; 3) open water hydraulic modelling; 4) open water flood inundation mapping; and 5) design flood hazard mapping.

No previous provincial flood study has been conducted for the Hamlet of Robb; however, a flood plain study was carried out by Associated Engineering (2001) for Yellowhead County.

1.2 Study Objectives

The primary tasks, services, and deliverables associated with this report are:

- Conduct stream cross section surveys.
- Collect data on hydraulic structures.
- Conduct a field survey and integrate data from the digital terrain model (DTM).
- Document flood history.
- Conduct open water hydrology assessment to determine flood frequency estimates.
- Develop a one-dimensional (1D) open water hydraulic model.
- Simulate open water floods for 13 return periods and create water surface profiles throughout the study reach.
- Perform sensitivity analysis on selected modelling parameters.
- Produce flood inundation maps for selected return periods.
- Determine floodway criteria and boundary line.

- Produce floodway criteria and design flood hazard maps.

1.3 Study Area and Reach

Figure 1.1 shows the location and boundaries of the study area, which includes:

- 10 km Embarras River extending from its south boundary at SE 10-49-21-W5M to its north boundary at NE 23-49-21-W5M,
- 3 km Bryan Creek extending from its west boundary at NE 16-49-21-W5M to its confluence with the Embarras River.

The study area includes the Hamlet of Robb and a portion of Yellowhead County, and is located 50 km southwest of Edson, AB and 45 km southeast of Hinton, AB.

River cross section surveys were extended beyond the downstream boundary of Embarras River to accommodate hydraulic modelling and inundation mapping requirements.

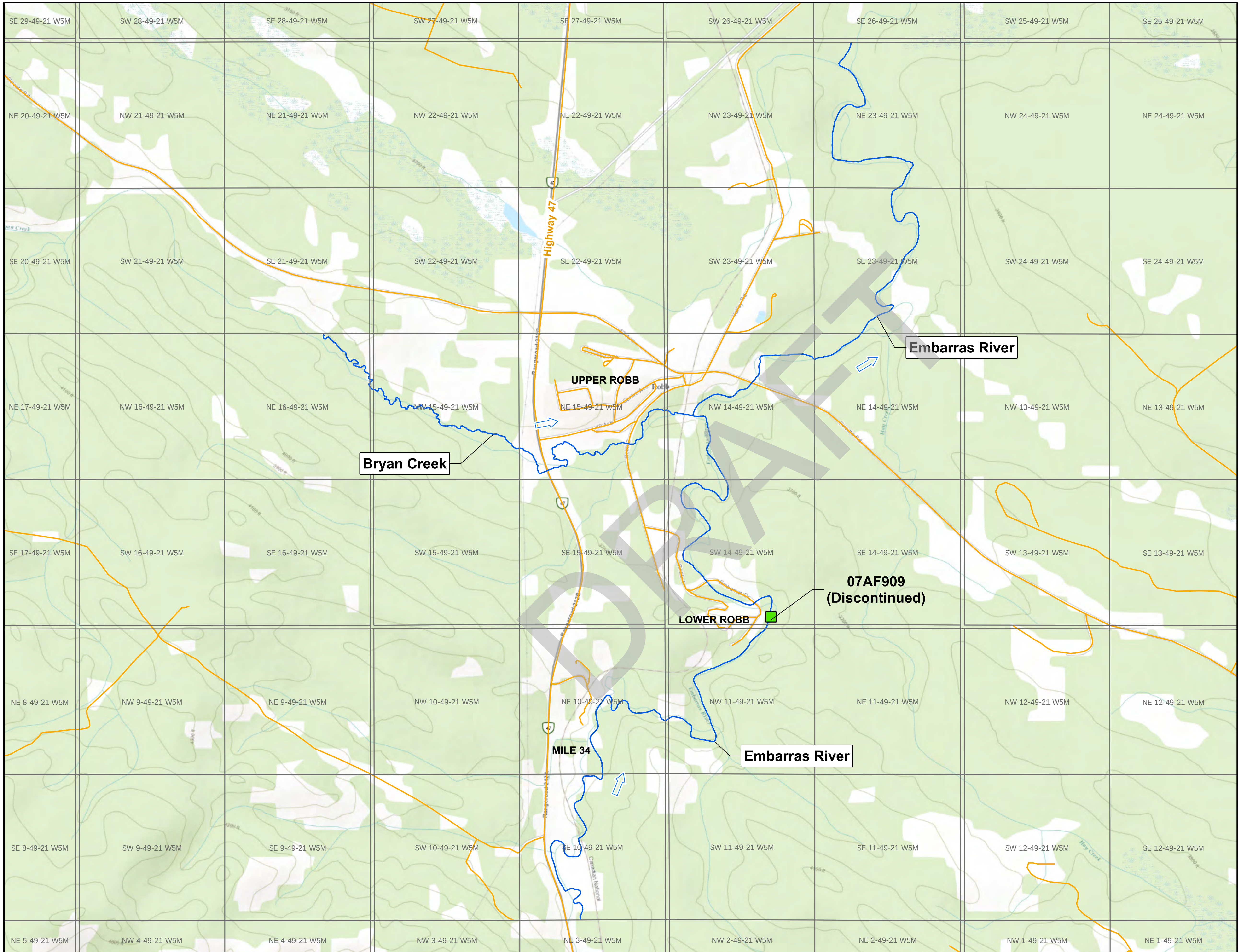
1.4 River and Basin Settings

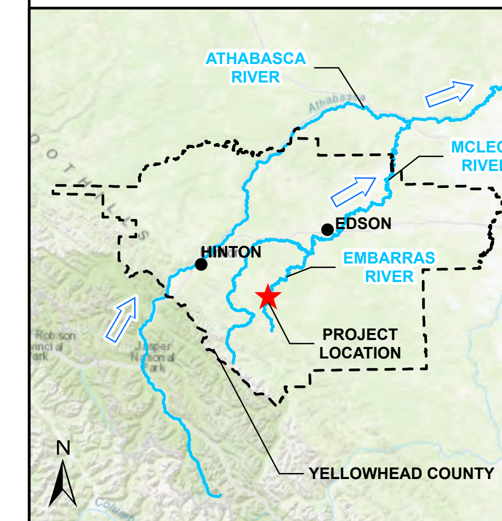
The Embarras River is a major tributary of the McLeod River, which is a tributary of the Athabasca River. The river is a foothills stream, which originates in the mountain foothills east of Jasper National Park, and flows north through the Hamlet of Robb, Alberta. From there, it flows northeast for approximately 80 km to its confluence with the McLeod River.

Bryan Creek is a tributary of the Embarras River. It flows in an easterly direction through the Hamlet of Robb before joining the Embarras River. Bryan Creek discharges to the Embarras River from a box culvert through a CN railway embankment.

Figure 1.2 provides an overview of the Embarras River and Bryan Creek study basins, illustrating the drainage areas for Embarras River (167 km^2) and Bryan Creek (24.2 km^2) within the study area. These drainage areas were determined based on the Water Survey of Canada (WSC) station information, National Hydrometric Network Basin Polygons (Government of Canada, 2024), and LiDAR 15 m digital elevation model (DEM) data.

Figure 1.2 also illustrates the study area basins overlaid on Alberta's natural subregions map. Alberta's land classification system divides the province into six natural regions and 21 subregions, defined by geographic patterns of vegetation, soil, and physiographic features that reflect the combined influence of climate, hydrology, topography, and geology. Most of the study area basins lie within the Upper Foothills subregion. However, the lower portion of the Embarras River basin below Robb, along with part of the Bryan Creek basin, falls within the Lower Foothills subregion. The Upper Foothills is cooler and wetter with shorter summers and higher precipitation, while the Lower Foothills is warmer and drier year-round with slightly less precipitation due to stronger continental climate influence.





FLOW DIRECTION
STUDY REACH
ROAD
ATS QUARTER SECTION
WSC GAUGE STATION

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:20,000

0 250 500 750 M

N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

FLOOD STUDY REACH

FIGURE 1.1

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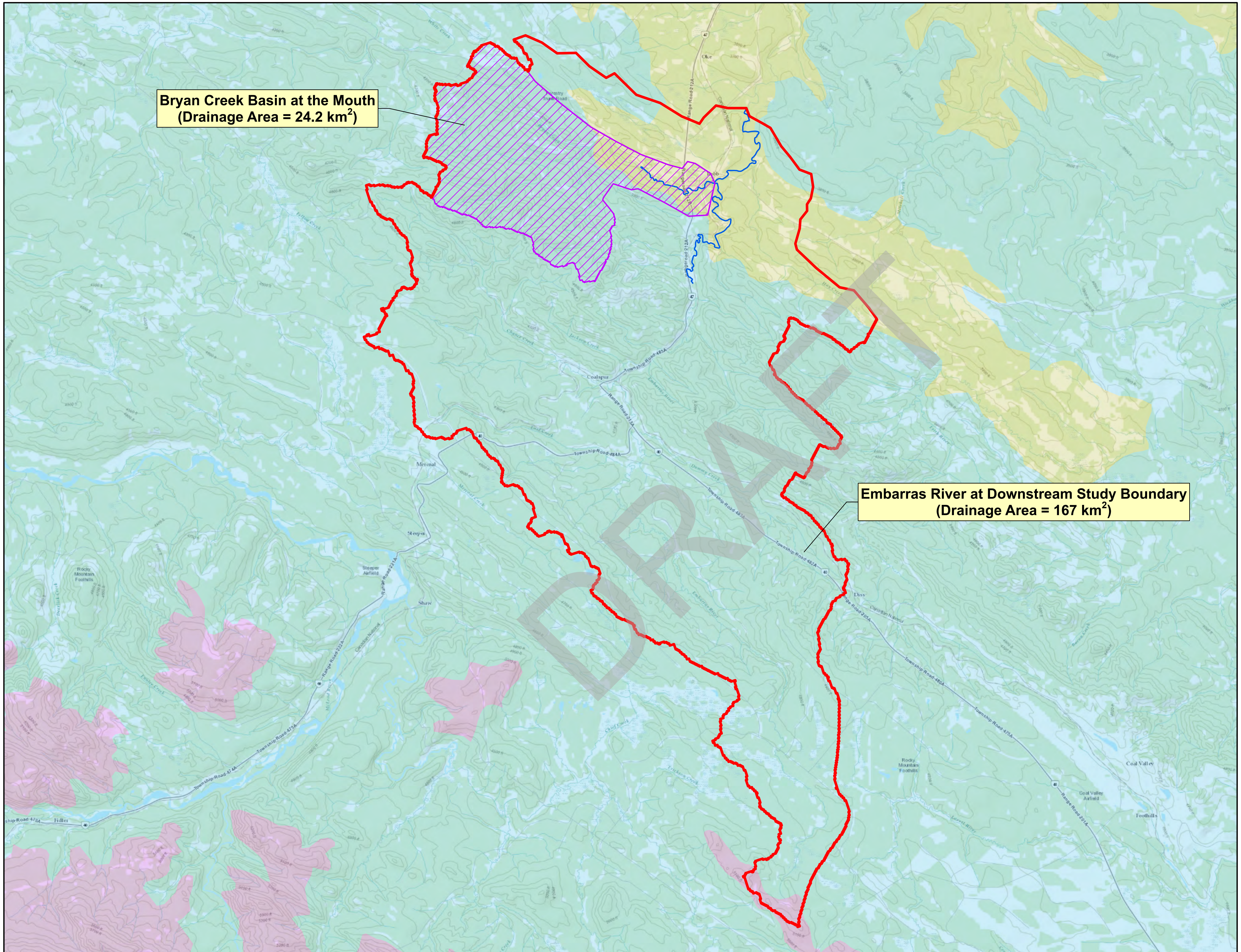
Classification: Public



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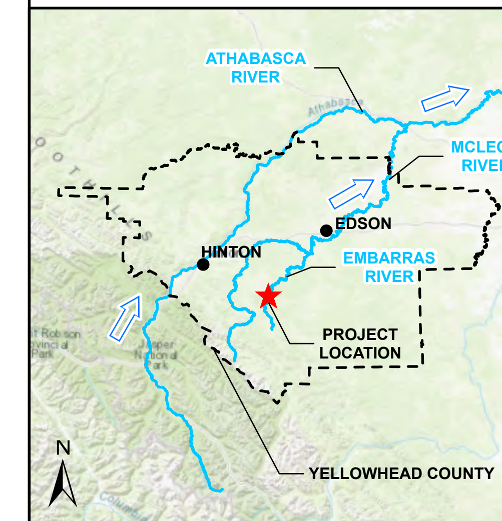

- STUDY REACH
- BRYAN CREEK AT THE MOUTH
- EMBARRAS RIVER AT DOWNSTREAM STUDY BOUNDARY
- SUBALPINE NATURAL SUBREGION
- UPPER FOOTHILLS NATURAL SUBREGION
- LOWER FOOTHILLS NATURAL SUBREGION

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:100,000

0 1 2 3 KM

N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

BASIN OVERVIEW

FIGURE 1.2

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2 SURVEY AND BASE DATA COLLECTION

2.1 Survey Procedures and Methodology

The survey program was completed between 15 and 19 October 2024. The objective of the survey program was to survey channel cross sections along the study reaches to support the development of a 1D hydraulic model. Prior to the survey, a site visit was carried out on 20 September 2024, to inspect the study reach, assess the overall condition of the channel and floodplain, and plan the survey program. After the site visit, the survey plan was submitted to and approved by EPA.

Ground positioning for the survey was measured using Global Navigation Satellite Systems (GNSS) and Trimble R12 Real Time Kinetic (RTK) GNSS receivers. Elevations in the channel and on the ground along the channel banks and in floodplains were directly measured with the RTK GNSS receiver attached to a survey rod. The surveyed cross sections included the riverbanks and extended into the floodplain, overlapping with the DTM provided by EPA.

The Trimble RTK GNSS receivers used in the survey can provide an accuracy of ±0.02 metres under optimal conditions when mounted on a tripod with a clear view of the sky, and sufficient satellite coverage. Additional errors may occur if the receiver is off-level or obstructed by trees or vegetation. The expected accuracy of ground-based survey points is ±0.05 metres, except in rare cases where points are surveyed in tree cover or near large vertical banks, resulting in poor satellite coverage. The accuracy of the survey data collected falls within the tolerance specified in the FHIP Flood Study Technical Guidelines (AEP, 2022).

2.1.1 Coordinate System and Datum

Horizontal positions were referenced to the three-degree Transverse Mercator (3TM) projection with a central meridian of 117°W. The 3TM projection is part of the Canadian Spatial Reference System (CSRS) North American Datum of 1983 (NAD83); it is a three-dimensional grid on which the position of an object or feature can be precisely pinpointed. Orthometric heights are based on the Canadian Geodetic Vertical Datum of 1928 (CGVD28) and HTv2.0 hybrid geoid model.

2.1.2 Control Network

A control point network was established from local available permanent and temporary benchmarks and GNSS surveying to provide a spatial reference for the survey program. Three NHC project survey control points, one Natural Resources Canada (NRCan)/ Alberta Survey Control Marker (ASCM) permanent benchmark, three temporary benchmarks used during the project LiDAR data collection, and five temporary benchmarks from EPA 2023 highwater mark

(HWM) surveys were tied into the current survey. A list of the control point coordinates is provided in Table 2.1[1].

Table 2.1 Control point summary

Name	Type	Easting (m)	Northing (m)	Elevation (m)	Measurement Type
NHC Control 1	NHC project control point	982.247	5897541.957	1133.583	Static Measurement
NHC Control 2		1207.661	5900426.096	1131.541	
NHC Control 3		2227.090	5902023.733	1089.028	
NRCan 896011/ASCM 959130	NRCan/ASCM permanent benchmark	-569.445	5893428.271	1193.087	RTK Measurement
Emb-Robb-1	EPA temporary benchmark used during 2023 HWM survey	1851.766	5898929.432	1104.981	
Emb-Robb-2		2129.711	5898807.513	1106.503	
Emb-Robb-3		2132.115	5898722.474	1106.887	
Emb-Robb-4		2094.411	5900010.318	1091.542	
Emb-Robb-5		2127.042	5900046.965	1091.193	
Lidar-2	Temporary benchmark used for LiDAR survey	1021.423	5898402.352	1150.373	
Lidar-3		981.827	5897532.015	1133.771	
Lidar-4		1368.689	5899734.603	1109.584	

The coordinates for three of the NHC project control points were determined by running the GNSS receivers simultaneously in static mode for more than three hours at each control point. This was done to obtain precise point positioning (PPP) results from the Canadian Spatial Reference System (CSRS). The data was then post-processed using Trimble Business Center software to adjust the network by establishing baselines between control points.

The control network adjustment was constrained to NHC Control 2, which was centrally located in the survey area and had the longest occupation time (five hours) and the most redundant data collected on it. The CSRS-PPP results estimated the total standard deviation of 95%, accounting for both PPP and epoch transformation uncertainties. At NHC Control 2, the total horizontal uncertainty was determined to be 0.028 m (easting) and 0.039 m (northing), with a total vertical uncertainty of 0.034 m. The horizontal and vertical errors at the other two control points, after post-processing and adjustment to the reference CSRS-PPP values, are summarized

[1] All coordinates presented in Table 2.1 are NHC survey coordinates.

in Table 2.2. The largest horizontal error was 0.0101 m, and the largest vertical error was 0.0219 m.

Table 2.2 Control network errors

Name	Easting (m)	Northing (m)	Elevation (m)
NHC Control 1	0.0010	0.0101	0.0217
NHC Control 3	0.0024	-0.0040	-0.0219

A comparison of the post-processed and adjusted surveyed elevations with benchmark elevations from external sources, such as published permanent benchmarks or temporary benchmarks established and surveyed by others, is provided in Table 2.3. The mean elevation residual is approximately 0.008 m, indicating strong vertical agreement between the control network and local benchmarks. Mean horizontal residuals are 0.238 m in easting and 0.092 m in northing, reflecting good overall horizontal consistency as well.

Table 2.3 Comparison between surveyed coordinates and published ASCM coordinates

	Type	Residuals (Surveyed Minus Published)		
Name		Easting (m)	Northing (m)	Elevation (m)
NRCan 896011/ASCM 959130	Permanent benchmark (NRCan/ASCM)	0.166	-0.082	0.035
Emb-Robb-1	Temporary benchmark used during 2023 HWM survey by EPA	0.014	0.018	-0.043
Emb-Robb-2		-0.012	0.001	-0.002
Emb-Robb-3		0.066	-0.064	-0.005
Emb-Robb-4		-0.041	0.002	-0.004
Emb-Robb-5		0.009	-0.018	0.004
Lidar-2	Temporary benchmark used for LiDAR survey by others	0.423	0.352	0.020
Lidar-3		0.827	0.015	0.042
Lidar-4		0.689	0.603	0.029

2.2 Digital Terrian Model

For this study, a non-hydro-flattened DTM was provided by EPA in January 2025, constructed from LiDAR data gathered in the spring of 2024 by Airborne Imaging Inc.

Elevations extracted from the DTM were compared with selected ground survey points collected by NHC on roads and other high ground. On average, the elevation difference between the DTM and ground survey points was approximately 0.014 m within the sampled data and the DTM was deemed suitable for model development.

2.3 Aerial Imagery

No new aerial imagery was collected for this project. EPA provided relatively recent SPOT satellite imagery (RGB, 1.5 m resolution) from October 2023, which was used for survey planning and hydraulic model setup. However, after consulting with EPA, NHC used available ArcGIS basemap satellite aerial imagery (captured in September 2024 around the study area) as the background imagery for flood maps due to its higher resolution.

2.4 Cross Sections and Bathymetry

Cross section locations were selected to ensure adequate representation of the channel geometry in the hydraulic model. During the planning process for the survey, each cross section was assigned a planned cross section (PXS) identifier to organize the cross sections sequentially and to associate survey point data with a PXS. The cross sections were surveyed between 15 and 19 October 2024. The PXS cross section and survey point locations are shown on maps provided in **Appendix A**.

A total of 111 cross sections were surveyed along the study reaches, 83 along the Embarras River and 28 along Bryan Creek. To minimize uncertainties in the hydraulic modelling results caused by downstream boundary conditions, the survey was extended approximately 1 km beyond the downstream limit of the Embarras River study reach. Table 2.4 provides details on the minimum, maximum, and average spacing of cross sections surveyed in each reach.

Table 2.4 Cross section survey summary

Reach	Reach Length (km)	Number of Cross Sections	Average Spacing (m)	Minimum Spacing (m)	Maximum Spacing (m)
Embarras River	10.8	83	132	10	354
Bryan Creek	3.4	28	124	43	235

The average surveyed cross section spacing for Embarras River was 132 m. The minimum spacing was 10 m, occurring between PXS-77 (RS 9,887 m) and PXS-76 (RS 9,877 m) on either side of the CN Railway Bridge. The maximum spacing was 354 m on a relatively straight reach between PXS-27 (RS 4,293 m) and PXS-26 (RS 3,939 m).

The average cross section spacing for Bryan Creek was 124 m. The minimum spacing was 43 m, occurring between PXS-91 (RS 553 m) and PXS-90 (RS 510 m) on either side of Valley Road Culvert. The maximum spacing was 235 m between PXS-97 (RS 1,319 m) and PXS-96 (RS 1,084 m), situated just downstream of Highway 47 Culvert.

All the survey point data were assembled and provided in the digital file submission.

2.5 Hydraulic Structures

The hydraulic structures surveyed during the field program include five bridges and four culvert crossings as listed in Table 2.5, along with the corresponding Alberta Transportation and Economic Corridors (TEC) bridge file numbers when available. The locations of these structures are shown in survey overview maps provided in **Appendix A**. Survey data collected for the bridge included: span length; deck width; top of curb or solid guardrail elevation; low chord elevation; number, width, type, shape, and location of piers; top of deck elevation; and photographs of the bridge. Information collected for the culvert included: culvert type; shape; dimensions and length; entrance condition; upstream and downstream invert elevation; crest elevation; and photographs of the culvert. In addition, bridge and culvert design drawings were collected as available to complement the survey data. Details of each hydraulic structure is provided in **Appendix B**.

Table 2.5 Hydraulic structure survey summary

River	River Station (m)	Crossing Description	Structure Type	TEC Bridge File No.
Embarras River	9,882	CN Railway	Bridge	
	9,017	Private Crossing	Bridge	
	6,862	Embarras Drive (South)	Bridge	70587
	6,543	Embarras Drive (North)	Bridge	76138
	4,541	Township Road 492A	Culvert	
	3,274	Old Railway	Bridge	
Bryan Creek	1,352	Highway 47	Culvert	70904
	528	Valley Road	Culvert	73286
	49	CN Railway	Culvert	

2.6 Flood Control Structures

The FHIP Guidelines (AEP, 2022) describes a flood control structure as a permanent barrier or engineering system that keeps water from entering and flooding an area up to a design water level and can be overtopped if flood levels exceed the height of the berms at one or more locations. Flood control structures are often earthen berms but can be other types of flood barriers constructed of concrete, steel, or other materials.

Dedicated flood control structures, such as berms, typically require regulatory approval prior to construction, are owned, operated, and maintained by a local authority or other government entity, and are officially recognized by EPA and local authorities as flood management infrastructure.

Some road and railway embankments or berms may perform as flood barriers and affect the river hydraulics but may not be dedicated flood control structures. Railroad embankments are typically assumed to be permeable and are not treated as natural ground features or dedicated flood control structures in flood studies.

Based on the site visit, survey, and discussions with EPA and Yellowhead County, NHC concluded that there are no specifically designated flood control structures within the study area.

2.7 Additional Data

Additional data comprises site photographs, gathered during the site visit and survey, encompassing both ground shots and aerial drone shots. Hydraulic structure drawings and base mapping features were also collected as integral components of the project.

2.7.1 Hydrometric Gauging Station Information

There are no active WSC gauging stations within the study reach of Embarras River and Bryan Creek. Thus, no WSC benchmarks are available to compare against the control network.

2.7.2 Discharge and Water Level Measurements

As part of the survey program, NHC measured discharge and corresponding water levels at the Embarras River and Bryan Creek study reaches. Discharge measurements were taken at three selected transects, two along Embarras River and one along Bryan Creek. Water levels were recorded throughout Embarras River and Bryan Creek in conjunction with the discharge measurements.

Discharge measurements were done using a Sontek FlowTracker Acoustic Doppler velocimeter (ADV) mounted to a wading rod. The ADV reports velocity measurements to an accuracy of ±2.5 mm/s. Table 2.6 summarizes the discharge measurements for Embarras River and Bryan Creek carried out on 18 October 2024.

Table 2.6 Summary of discharge measurements

River	Reach	Date	Discharge (m^3/s)	Location Remarks
Embarras River	Above Bryan Creek	18 October 2024	0.22	Close to upstream study boundary (upstream of CN Railway Bridge)
	Below Bryan Creek	18 October 2024	0.26	Downstream of Township Road 492A Culvert Crossing
Bryan Creek	Main	18 October 2024	0.04	Upstream of Valley Road Culvert Crossing

All measured discharges were significantly low and not representative of flood conditions.

2.7.3 Site Photographs

Appendix C provides annotated reach representative photographs obtained during the site visit and survey program. The location, time, and other metadata information are embedded in the electronic images included as part of the digital file submission.

2.7.4 Hydraulic Structure Design Drawings

NHC requested design drawings for bridges through EPA, TEC, Canadian National Railway Company (CN Rail), and Yellowhead Country. Information was obtained for the following structures:

- Embarras Drive (South) Bridge (BF70587)
- Embarras Drive (North) Bridge (BF76138)

2.7.5 Base Mapping Features

In addition to the datasets listed above, other base mapping data were obtained to support modelling and mapping for the study, including road network, hydrography, administrative boundaries, topographic maps, and Alberta Township System (ATS) grids within the study area.

3 FLOOD HYDROLOGY

This section provides a summary of flood hydrology for the study area. A more detailed assessment of open water hydrology is provided in the Open Water Hydrology Assessment Memorandum in **Appendix D**.

3.1 Flood History

A summary of the local flood history, encompassing both open water and ice affected floods, was prepared to provide context for the development and calibration of the hydraulic model. NHC explored and reviewed the following sources to document major flood events in the study area:

- Embarass River at Robb Flood Frequency Analysis (AENV, 1984)
- Athabasca River Basin Planning Program – Urban Flood Damage Reduction Component (Ecos & IBI, 1988)
- Floodplain Study for the Hamlet of Robb (Associated, 2001)
- Feasibility Study – Athabasca River Basins (IBI & Golder, 2014)
- TEC bridge file for Embarras Drive Bridge crossings (BF #76138 and #70587)
- Discussion with local people and stakeholders

3.1.1 General Information

Long-term flow data are not available for the study reaches. The only WSC gauge station within the study area, WSC Station 07AF909 (Embarras River at Robb), was discontinued and provides only seasonal daily flow measurements from 1984 to 1988. Long-term flow monitoring data (1984-present) for the Embarras River are available at WSC Station 07AF014 (Embarras River near Weald), located farther downstream with a larger drainage area of 640 km^2. Despite this difference in drainage area, data from WSC Station 07AF014 can be used to characterize flood patterns within the study area due to similar climatic and physiographic conditions.

3.1.2 Open Water Floods

The most annual open water peak flows in the Embarras River occur between June and July, driven by snowmelt combined with major rainstorms in the foothills region.

Recent and Recorded Open Water Floods

The largest recorded flood on the Embarras River near Weald, based on data from WSC Station 07AF014, occurred in June 2023, with a peak daily flow of 179 m^3/s (estimated by WSC) and an instantaneous peak flow of 211 m^3/s (estimated by NHC) for this study. Peak flows within the study reach were also assessed by NHC, as outlined in Section 4.3.3. EPA carried out a HWM survey approximately six days after the 2023 flood peak. As part of this project, NHC and EPA also conducted a site visit in September 2024. Post 2023 flood photographs were taken during both visits and are shown in Figure 3.1.

The second-largest flood at WSC Station 07AF014 was recorded in early August 1987, with an instantaneous peak flow of 145 m^3/s, followed closely by a peak of 143 m^3/s in July 1999.

Historical 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.

Systematic flow records for the Embarras River do not exist prior to 1984. However, historical flood levels at the Embarras Drive bridge (located in lower Robb), documented in TEC bridge file #76138 and #70587, highlighted two major floods in July 1965 and August 1969. Another significant flood occurred in the region in 1980, with an estimated return period of approximately 35 years (AENV, 1984). Peak discharge estimates were not available for any of these floods.

Flood photographs are available from July 1965 flood (Figure 3.2), which show the washout of Old Embarras Drive bridge.

3.1.3 Ice Jam Floods

Ice jams have not been a cause of flooding in the study area based on the available information.

3.2 Flood Frequency Analysis

An open water flood frequency analysis was carried out to determine estimates of flood frequencies for a range of return periods up to 1000 years. Details on the flood frequency analysis are provided in the Open Water Hydrology Assessment Memorandum in **Appendix D**.

3.2.1 Flood Frequency Flow Estimates

Flood frequency estimates were calculated for 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water flood events at the three selected flood frequency estimate locations along the Embarras River and Bryan Creek study reaches. The flood frequency flows were estimated based on the regional analysis. The adopted flood frequency estimates are presented in Table 3.1 along with their 95% confidence limits.

(a)

(b)

(c)

Notes:
a) A house in the Mile 34 area was impacted by bank erosion along the Embarras River during the 2023 flood (photo taken on September 27, 2024).
b) Debris from the 2023 flood is obstructing a side channel of the Embarras River, just downstream of the Mile 34 area (photo taken on September 27, 2024).
c) Flood debris from 2023 is blocking the entrance of the Township Road 492A culvert (photo taken by EPA on June 26, 2023).

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Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

2023 POST-FLOOD PHOTOGRAPHS

FIGURE 3.1

Notes: a) West Side, looking north. Old Embarras Drive Bridge completely washed out. (photo obtained from TEC bridge file #76138 flood documentation).

Alberta Canada		ROBB FLOOD STUDY
nhc		**1965 FLOOD PHOTOGRAPH**
	Job: 1009252 / *Date: 28-AUG-2025*	FIGURE 3.2

Table 3.1 Flood frequency estimates from regional analysis

Return Period (years)	Peak Instantaneous Discharge (m³/s)								
	Embarras River above Bryan Creek			Embarras River at downstream study boundary			Bryan Creek at the mouth		
	Value	Upper 95% Limit	Lower 95% Limit	Value	Upper 95% Limit	Lower 95% Limit	Value	Upper 95% Limit	Lower 95% Limit
1000	103.0	123.1	89.1	132.5	158.3	114.6	28.2	33.8	24.4
750	99.0	118.2	85.7	127.3	151.9	110.2	27.1	32.4	23.5
500	93.1	111.0	80.7	119.7	142.7	103.7	25.5	30.4	22.1
350	88.2	104.9	76.5	113.3	134.9	98.3	24.2	28.8	21.0
200	80.0	95.0	69.5	102.8	122.1	89.4	21.9	26.0	19.1
100	70.0	82.8	61.0	90.0	106.5	78.4	19.2	22.7	16.7
75	66.0	78.0	57.6	84.9	100.2	74.0	18.1	21.4	15.8
50	60.1	70.7	52.4	77.2	90.9	67.4	16.5	19.4	14.4
35	55.0	64.6	48.0	70.7	83.0	61.8	15.1	17.7	13.2
20	46.8	54.8	40.9	60.2	70.4	52.6	12.8	15.0	11.2
10	36.7	42.9	32.0	47.2	55.1	41.1	10.1	11.8	8.8
5	26.6	31.2	22.6	34.2	40.2	29.0	7.3	8.6	6.2
2	12.9	16.8	8.7	16.6	21.6	11.2	3.5	4.6	2.4

3.2.2 Comparison with Previous Studies

Table 3.2 compares flood frequency estimates from the current regional analysis for the Embarras River above Bryan Creek with those from previous studies by AENV (1984) and Associated (2001). There is no previous provincial flood hazard mapping for the Hamlet of Robb, and none of the prior flood frequency estimates were linked to detailed flood mapping based on provincial guidelines and standards.

Table 3.2 Comparison with previous flood frequency estimates

Return Period (years)	Embarras River above Bryan Creek			Bryan Creek at the mouth		
	This Study	AENV (1984)	Associated (2001)	This Study	AENV (1984)	Associated (2001)
	Drainage Area (km²)					
	122	123	125	24.2		26
	Peak Instantaneous Discharges (m³/s)					
200	80.0	95.8		21.9		
100	70.0	82.7	158	19.2		33
50	60.1	67.6		16.5		
20	46.8	52.7		12.8		
10	36.7	40.0		10.1		
5	26.6	27.8		7.3		
2	12.9	12.6		3.5		

The current study generally estimates lower flood frequencies for the Embarras River above Bryan Creek than the AENV (1984) study, except for the 2-year flood. Peak flow differences range from 2% to 16%, largely due to differences in regional gauging station selection. AENV (1984) used three stations, including one in the Rocky Mountains and another with a drainage area over 15 times larger than the study basin, making them not homogeneous with the study basins. Limited regional data availability prior to 1984 probably led to including these stations in the regional analysis.

In contrast, the current study incorporates more representative stations (including one on the Embarras River), uses longer records, and includes recent events such as the 2023 flood. These factors improve accuracy and reduce uncertainty in the current estimates.

Differences with the Associated (2001) study are greater, its 100-year flood estimates are 56% and 42% higher for the Embarras River and Bryan Creek, respectively. The Associated study relied solely on data from WSC Station 07AF004 (Deerlick Creek near Hinton) and prorated the peak discharges to the study basin using a simple drainage area ratio without applying a power factor. However, using Deerlick Creek, a small basin with a drainage area of only 14.9 km², to predict flood flows for the more than ten times larger Embarras River basin, was considered inappropriate. In addition, the study did not evaluate the Pearson type III (P3) distribution, which has generally proven to best fit the flood peaks for the region. As a result, the flood frequency estimates by Associated (2001) are overly conservative and fall outside the acceptable range for this flood mapping study.

Overall, the differences between the current and previous studies reflect the impact of updated data and improved methodologies for flood frequency estimates.

4 HYDRAULIC MODELLING

This section provides an overview of the hydraulic modelling relevant to this study. It includes discussions on the data used in the modelling, the characteristics of the streams and valleys, the model development and calibration process, the results obtained from the model, and the model sensitivity analysis.

4.1 Available Data

Data pertinent to the development of the hydraulic model include basin hydrology, survey information, current high-resolution terrain data representing the floodplain, and calibration and validation datasets. The data available for this study are summarized below.

4.1.1 Survey and Base Data

The hydraulic modelling utilized the following survey and base data:

- cross section survey data gathered by NHC
- survey data on hydraulic structures such as bridges and culverts, collected by NHC
- water level survey data collected by NHC throughout the study reach.

In addition, the non-hydro-flattened DTM received in January 2025 was used for constructing the model. For additional details regarding the acquired survey and base data, refer to Section 2.

4.1.2 Previous Models

No prior provincial flood hazard mapping exists for the Hamlet of Robb; therefore, no hydraulic model has previously been developed to the standards outlined in provincial flood mapping guidelines. A hydraulic model was developed by Associated in 2001 as part of the Hamlet of Robb floodplain study commissioned by Yellowhead County. However, this model was not readily available and was not considered relevant to the current project.

4.1.3 Highwater Marks

HWM observations serve as documentation of the highest water levels reached at specific locations during a particular flood event. These observations are instrumental in calibrating and validating hydraulic models, as they allow for comparisons between simulated water levels and actual highwater mark elevations along the study reach.

To compile HWM data, a comprehensive review of various sources was conducted, including previous studies, the EPA database, TEC flood history documentation, and local historical archives. The most recent and reliable HWM data were collected by EPA following the June 2023 flood along the Embarras River. No HWM data was collected for Bryan Creek during this event. Additionally, no streamflow measurements were available for the 2023 flood, and the discharge was estimated as described in Section 4.3.3 below.

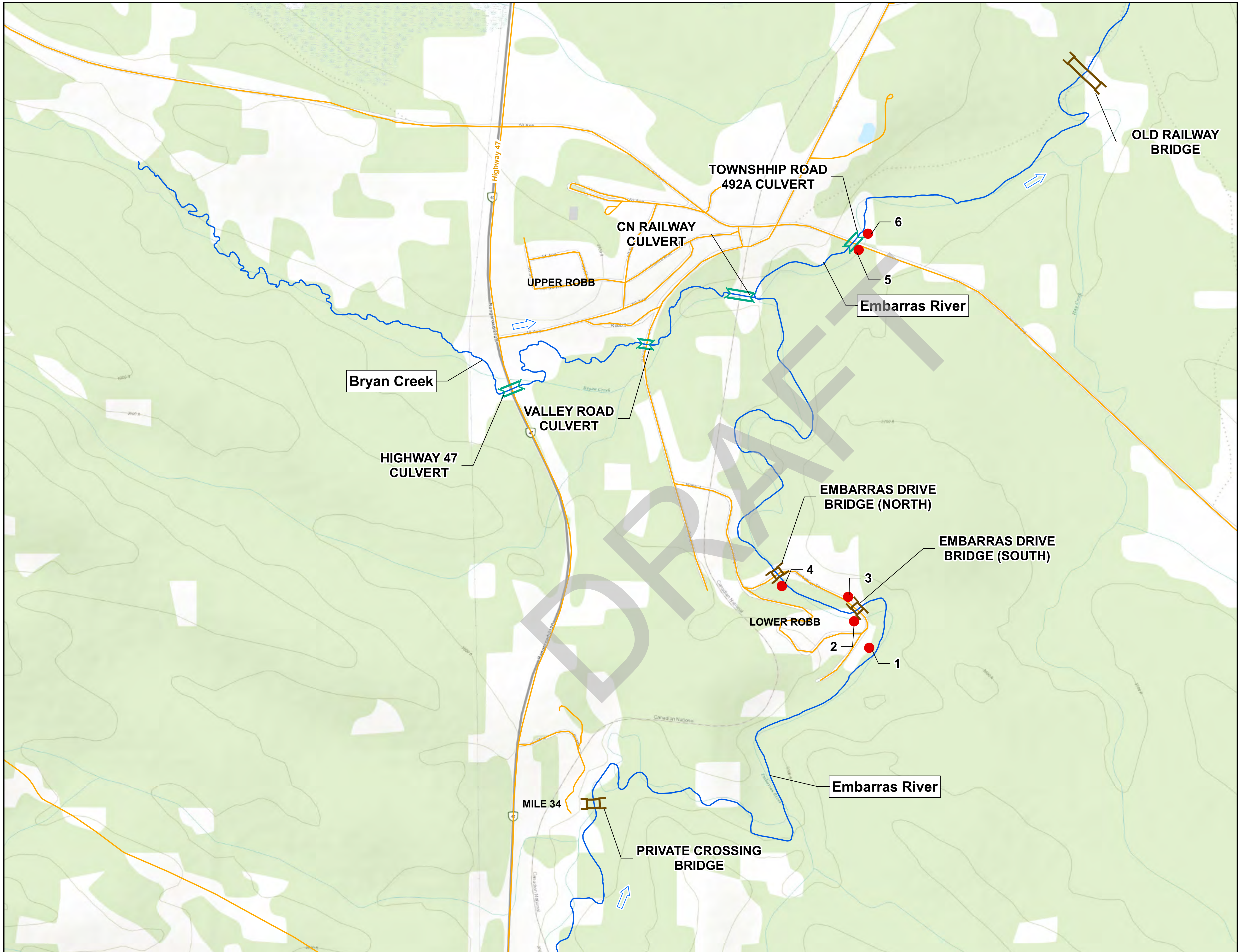
HWM references were also identified in TEC bridge file documentation, noting flood events from 1969, and 1986. However, discharge data for these historical events were not available and regional gauge flow data was insufficient to produce reliable flow estimates. In addition, establishing geodetic elevations for these flood events was challenging due to lack of clarity in the exact location of the HWM, and potential upgrades to bridges and culverts. Consequently, these older HWMs could not be used for model calibration or validation. Only the 2023 HWM data was deemed suitable for calibrating the hydraulic model.

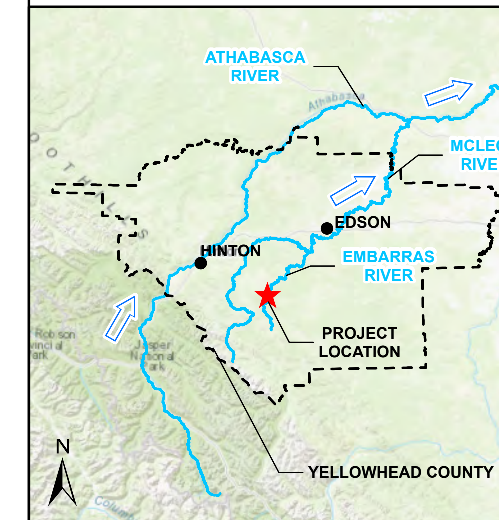
Table 4.1 summarizes the available 2023 HWM data, with corresponding locations shown in Figure 4.1. These locations were approximated using information specific to each HWM observation site (e.g. field notes, site photographs or comments on their location with respect to other features like bridges/houses).

As reported in Table 4.1, a 7.4 m drop was recorded between the HWMs upstream (Emb-Robb-4) and downstream (Emb-Robb-5) of the Township Road 492A Culvert. This indicates that the culvert lacked sufficient capacity to convey the 2023 flood. Consequently, a backwater zone developed upstream, producing higher water surface elevations, while downstream levels were significantly lower. This hydraulic behavior confirms that the culvert was highly submerged and acted as a major control point during the flood. The same condition was observed in the hydraulic modeling results, as discussed in later sections of this report.

Table 4.1 Summary of available 2023 HWMs

Event	River	Reach	HWM No.	HWM Name	HWM Description	River Station (m)	Estimated Discharge (m^3/s)	HWM Elevation (m)
20 June 2023	Embarras River	Above Bryan Creek	1	Emb-Robb-3 (HWM1)	Needle line on back of private berm (left bank)	7,143	60.1	1107.102
			2	Emb-Robb-2 (HWM1)	Flood line near shack downstream of Embarras Drive South Bridge (left bank)	6,838	60.1	1104.963
			3	Emb-Robb-2 (HWM2)	Debris Line along Embarras Drive close to south bridge (right bank)	6,833	60.1	1104.926
			4	Emb-Robb-1 (HWM1)	Debris line upstream of Embarras Drive North Bridge (left bank)	6,592	60.1	1103.095
		Below Bryan Creek	5	Emb-Robb-4 (HWM1)	Leaf line upstream of Township Road 492A Culvert (right bank along the road slope)	4,579	77.2	1093.630
			6	Emb-Robb-5 (HWM1)	Downstream of Township Road 492A Culvert (right bank)	4, 497	77.2	1086.253





FLOW DIRECTION
STUDY REACH
BRIDGES
CULVERTS
ROAD
JUNE 2023 HWMS

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:12,000
0 250 500 M
N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	RBA

Job Number	Date
1009252	28-AUG-2025

ROBB FLOOD STUDY

2023 HIGHWATER MARK LOCATIONS

FIGURE 4.1

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Classification: Public

4.1.4 2023 Post Flood Surveyed Water Levels

The HWM elevations for the 2023 flood along the Embarras River study reach were collected on 26 June 2023, 6 days after the peak. During the HWM survey, EPA also surveyed the river water levels at five locations (adjacent to the HWM locations).

The Embarras River within the study reach is ungauged and no discharge measurements were taken at the time of survey. Reliable discharge estimates could not be established for these water level observations. As a result, this data could not be used for model calibration or validation.

4.1.5 2024 Surveyed Low Flow Water Levels

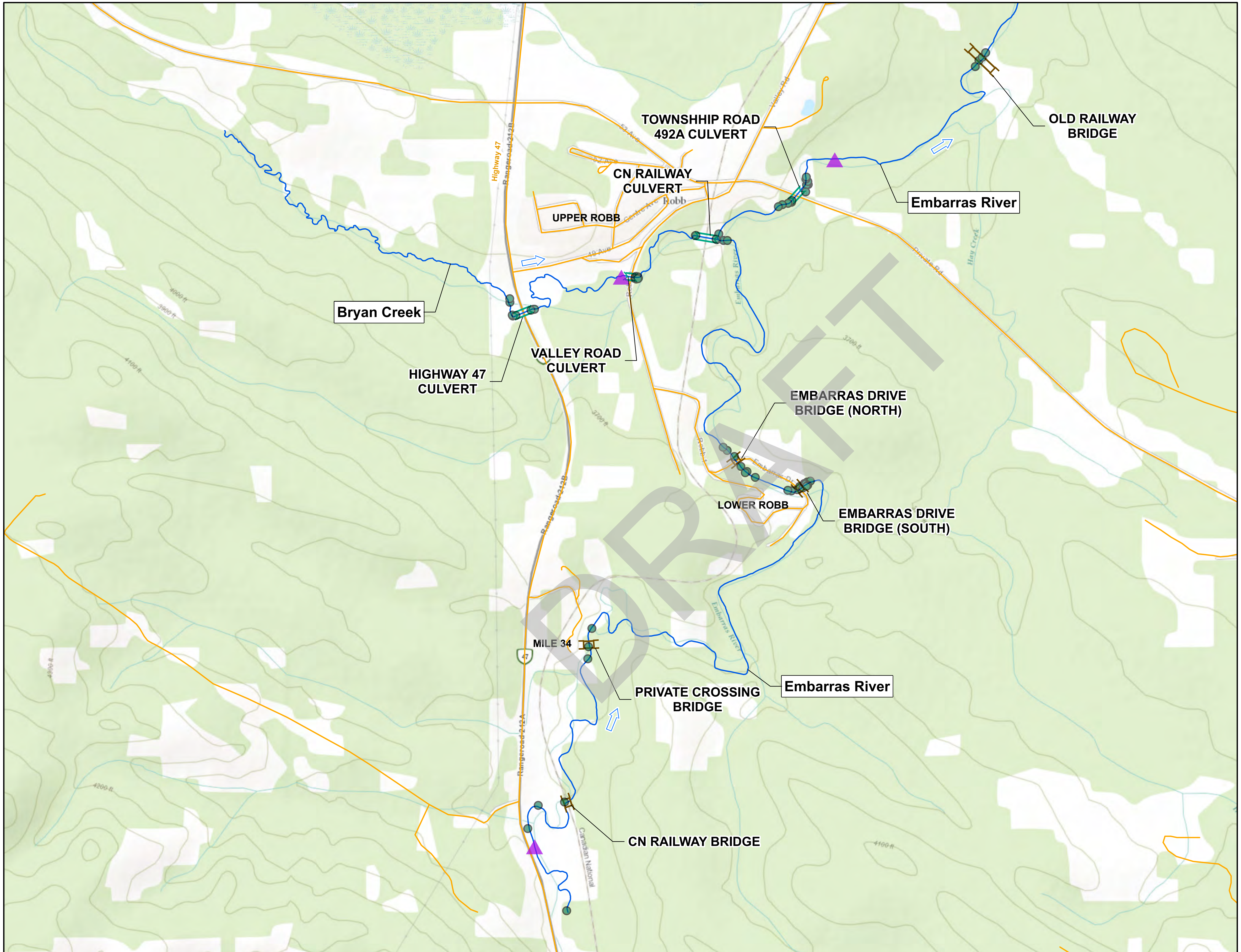
NHC surveyed water levels corresponding to the flow measurements (described in Section 2.7.2) along Embarras River and Bryan Creek on 18 October 2024. These surveys were conducted to represent the entire study reach. The locations of the surveyed water levels along with the flow measurement locations are illustrated in Figure 4.2. This additional dataset was used for low flow validation for the hydraulic model.

4.1.6 Gauge Data and Rating Curves

The relationship between stage (water level) and discharge at a gauging station is established by the WSC using recorded stage data and direct discharge measurements. This relationship is represented by a curve fitted to the observed data, commonly known as a rating curve. However, since there are no active WSC gauges within the study reaches, no rating curve data is available for this study.

4.1.7 Flood Photographs

Ground flood photos are available for 1965 and 2023 open water floods, which are referenced in the flood history section (Section 3.1).



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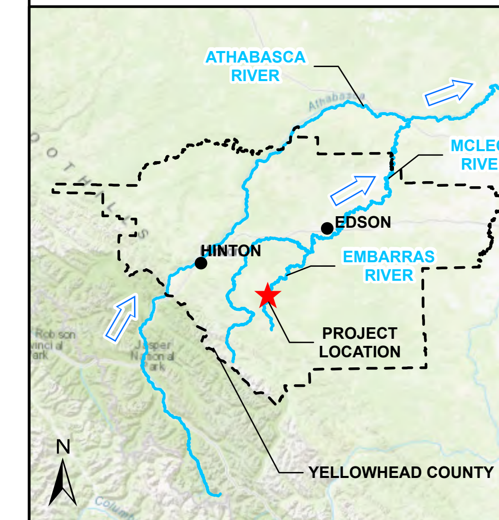


FLOW DIRECTION
STUDY REACH
BRIDGES
CULVERTS
ROAD
18 OCT 2024 SURVEYED WATER LEVELS
18 OCT 2024 NHC DISCHARGE MEASUREMENTS

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:15,000

0 250 500 M

N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	RBA

Job Number	Date
1009252	28-AUG-2025

ROBB FLOOD STUDY

LOCATION OF 2024 SURVEYED WATER LEVELS AND FLOW MEASUREMENTS

FIGURE 4.2

L:\S_P\1_Projects (Active)\1009252 Robb Flood Study\90_GIS\FIGURES\1009252 RFS FIGURES.aprx

4.2 River and Valley Features

This section describes the channel and floodplain characteristics of Embarras River and Bryan Creek within the study area.

4.2.1 General Description

The Embarras River originates in the eastern slopes of the Rocky Mountain foothills in Alberta and flows predominantly through forested and rugged terrain within the Foothills Natural Region. It flows northward through the Hamlet of Robb, before turning northeast and continuing for approximately 80 kilometers to its confluence with the McLeod River, southwest of Whitecourt, Alberta. The Embarras River is part of the larger Athabasca River basin, flowing ultimately into the Mackenzie River system and the Arctic Ocean.

Bryan Creek is a smaller tributary of the Embarras River. It flows in an easterly direction through the Hamlet of Robb before joining the Embarras River.

4.2.2 Channel Characteristics

The Embarras River study reach is a typical foothills stream characterized by a moderately sinuous channel and well-defined banks. The channel displays a combination of natural meanders and straightened segments, shaped by both natural processes and past land use or infrastructure development. The riverbed is primarily composed of gravel and cobbles, with occasional large boulders. Bank vegetation is moderately dense, consisting of shrubs, grass, and mostly coniferous trees. Large woody debris, likely deposited during flood events, is scattered throughout the channel and contributes to localized variations in flow and sediment deposition.

Bryan Creek flows through the Hamlet of Robb within a more confined channel. The creek is relatively steep, narrow, with grassy and sparsely wooded banks. The channel bed material in Bryan Creek is similar to what has been observed in the Embarras River based on NHC's field observations, consisting mainly of gravel and cobbles, with some occasional large boulders.

Channel slopes and top-of-bank widths vary along both the Embarras River and Bryan Creek. Average values for each reach are provided in Table 4.2.

Table 4.2 Summary of average channel slopes within the study reaches

River	Reach	Average Channel slope (m/m)	Average Channel Width (m)
Embarras River	Above Bryan Creek	0.0074	23
	Below Bryan Creek	0.0050	24
Bryan Creek	Main	0.0095	10

4.2.3 Floodplain Characteristics

The floodplains are mainly composed of developed/built-up areas and tree-covered zones. Developed areas include residential buildings, yards, open spaces, and transportation corridors. The most developed sections of the floodplain are found near Mile 34, Lower Robb, and Upper Robb. Outside of these areas, the floodplain is predominantly forested, characterized by dense stands of willow and trees.

4.2.4 Anthropogenic Features

The study area encompasses the Hamlet of Robb and a portion of Yellowhead County, featuring several key anthropogenic features:

- Three community areas within the hamlet: Mile 34, Lower Robb, and Upper Robb.
- Nine crossings along the study reach, consisting of five bridges and four culverts (as listed in Table 2.5), which provide access for roads, railways, and private properties.
- Predominantly residential buildings are located in Mile 34, Lower Robb, and Upper Robb areas and within the floodplain along the study reaches.
- The Coal Branch Hotel, situated on the left bank of Bryan Creek in the Upper Robb area.
- A few private cabins located on the right bank of the Embarras River, near the Mile 34 area.

4.3 Model Construction

This section discusses the hydraulic model development, calibration, model parameter selections, model results, and model sensitivity analysis.

4.3.1 General Methodology

The U.S. Army Corps of Engineer's Hydrologic Engineering Center- River Analysis System (HEC-RAS) computer program (Version 6.5, 2024) was used to perform hydraulic modelling and calculate the flood levels along the study reaches. HEC RAS can perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for a network of channels, hydraulic structures, and overbank areas.

For this study, a 1D hydraulic model was developed to calculate water surface profiles under steady-state flow conditions. The 1D HEC-RAS model requires several key inputs, including cross sections distributed along the study reach that define the geometry of the river channel and adjacent floodplain, Manning's roughness values for both the channel and overbank areas at each cross section, and appropriate upstream and downstream boundary conditions. The steady-state flow analysis employed in this study is based on solving the 1D energy equation, which accounts for energy losses due to channel friction as well as flow expansion and contraction between cross sections.

The analytical approach employed by HEC-RAS has the following assumptions and potential limitations:

- Flow is gradually varied and boundary friction losses between cross sections are estimated by Manning's equation using section-average parameters.
- The geometry is assumed to be fixed; therefore, changes in the channel and floodplain geometry (e.g. erosion or scour) that may occur during a flood are not accounted for.
- Each model cross section is apportioned into three separate conveyance components representing the main channel, left overbank, and right overbank; and the water level is assumed to be constant across all three conveyance components.
- The flow is one-dimensional (1D); therefore, only the velocity component in the principal direction of flow is accounted for in the model.

Supplementary 2D Modelling

A supplementary 2D model was developed for the study area (including Embarras River and Bryan Creek) based on the DTM data only. The model was preliminary in nature and was primarily used to guide the initial 1D model construction, such as defining overbank cross section alignments, overbank flow paths, and ineffective flow areas. The 2D model was also used to define the preliminary 1000-year inundation extents, which were then used to establish the initial 1D model domain and flood mapping boundary. These extents were subsequently verified and refined throughout the model development and simulation process.

1D Geometric Layout

NHC employed the following approach to develop key components of the model's geometric layout:

- Defined the channel centreline along the middle of the main channel and digitized it using ArcGIS and RAS Mapper tools and by visual referencing the DTM, hillshade, and aerial imagery.
    - Created a single, continuous centreline to represent each modelled reach.
    - Extended the study reach 1 km downstream beyond the study limit at the Embarras River, resulting in a total modelled reach of approximately 14 km including Embarras River and Bryan Creek.
- Digitized the model cross section transects at each surveyed cross section as follows:
    - Digitized the main channel section over the surveyed channel and bank point data.

- Extended the main channel portion left and right across the floodplain (overbank areas).
- Aligned the overbank portions perpendicular to the anticipated path of the floodplain flows based on preliminary 2D modelling results and projected them far enough to extend beyond the 1000-year flood inundation extents.
- The cross section alignment was further refined to support the assumption of a uniform water level across each section. This refinement was guided by the results from the preliminary 2D model.
- Projected cross section elevation values from the survey point data onto the cross section lines using the RAS Mapper toolset through a conflation process.
- Determined elevations in the overbank areas by extracting elevation values from the underlying DTM along the cross section polylines.

- Determined the left and right banks (referred to as bank stations) by examining the geometry of cross sections and analyzing the DTM, aerial imagery, and survey data. These bank stations were strategically positioned to delineate the boundaries of the modelled left overbank, main channel, and modelled right overbank sections of the cross sections. Additionally, they were placed to reflect variations in roughness within both the channel and floodplains. It's important to note that while these model bank stations serve to represent hydraulic conditions within the channel and floodplain, they may not align with the actual banks of the main channel. Their primary function is to simulate the hydraulic behavior of the channel and its surrounding floodplains within the model framework.
- Created flow paths coincident with the river centreline and along the left and right floodplains, representing the length of the main channel, left overbank, and right overbank flow paths.
- Measured distances between cross sections along flow path lines. The model requires these distances for calculating energy losses between cross sections within the main channel and the left and right overbank areas.

Channel and Overbank Roughness

Manning's roughness values were used to simulate roughness in the modelled reaches. A minimum of three (one channel and two overbank) roughness values were used within each cross section. Manning's roughness is an empirical coefficient used to account for energy losses due to a combination of factors including surface roughness and channel sinuosity. Manning's roughness also varies somewhat with discharge (more prominent in the grassed channels) and this situation could be simulated by a flow roughness factor in hydraulic modelling. The Manning's roughness values adopted for the present study are discussed further in Section 4.3.4.

Expansion and Contraction Coefficients

To account for the effects of flow contraction and expansion losses on the energy balance between successive cross-sections, HEC-RAS uses a coefficient to multiply the absolute difference in velocity head. These coefficients typically range from 0.10 for gradual transitions to 0.80 for abrupt transitions, as described in Brunner (2016). In some specific cases, a higher expansion coefficient beyond this typical range may be necessary to represent rapid expansions to a wider floodplain, to reflect backwater transitions, and to ensure the simulation of realistic flood frequency profiles across all thirteen scenarios, with proper nesting between them (means that higher frequency floods should produce higher water levels compared to lower frequency floods).

Boundary Conditions

Boundary conditions are required at the inflow (upstream) and outflow (downstream) boundaries of the model. The inflow boundary condition for this model is the discharge. The outflow boundary condition can be a water level or a friction slope with which the water level will be calculated by HEC-RAS assuming a normal depth condition. NHC used a normal depth friction slope as the downstream boundary condition for this study.

Ineffective Flow Areas

Ineffective flow areas can be specified within portions of cross sections where water will pond but there is no appreciable flow. One common example of using ineffective flow areas is in cross sections upstream and downstream of a bridge or culvert where flow is obstructed by elevated road embankments. In HEC-RAS, ineffective flow areas can be defined as either a permanent or non-permanent type. Permanent ineffective flow areas stay ineffective regardless of the water surface elevation, whereas temporary ineffective flow areas become effective when the computed water surface elevation exceeds a threshold. The configuration of ineffective flow areas depends on site-specific circumstances and engineering judgement.

4.3.2 Geometric Database

The geometric database provides all the components of the HEC-RAS model geometry, including cross sections, internal hydraulic structures, and boundary conditions. Each component is described below. Additional information and data are provided as part of the electronic deliverables of the study.

Cross Section Data

A total of 111 cross sections were created and used to construct the model for this study. The steps taken to generate the cross section data were as follows:

- Cross section alignments within the channel were generally established based on the surveyed cross section alignments described in Section 2.4. The overbank portions were extended perpendicular to the anticipated flow direction and refined to maintain the assumption of a uniform water level along each section line, as guided by preliminary 2D model results. All cross section alignments were extended beyond the anticipated 1000-year flood inundation extents.
- Two separate station-elevation data sets were created for each cross section.
- The first data set was created by projecting surveyed data points perpendicularly onto the channel portion of the cross section line.
- The second data set was created by extracting elevation values from the DTM along the cross section lines excluding the channel portion covered by the survey data.
- The two station-elevation data sets were combined. For each cross section, the number of elevation points for the overbanks were reduced using the minimize-area-change point filter option in HEC-RAS, so that the total number of the points is within the HEC-RAS limit of 500 points.
- Distances between consecutive cross sections were established within the HEC-RAS model following the established channel centerline and central flow paths for the left and right overbank areas.

Cross section details are provided in **Appendix E**.

Hydraulic Structures

The constructed model comprises of five bridges and four culvert crossings. The alignments and positions of all the hydraulic structures were determined based on survey data. Hydraulic structure details are tabulated in **Appendix B.**

Key design information of these structures that was incorporated into the model is tabulated in **Appendix E**. For bridges, this includes abutments, high and low chords defining the bridge deck and the superstructure, and the arrangement, shape, and dimensions of the piers. For culverts, parameters include the length of the barrel and material, the shape including span and rise/diameter, and the upstream and downstream invert elevations. The road profile at each hydraulic structure crossing was extracted using DTM data along the road centerline.

4.3.3 Model Calibration

This section discusses the general model calibration methodology, high flow calibration, and low flow validation.

Methodology

Calibration Parameters

Model calibration involves the selection and adjustment of model parameters such that computed flood levels agree well with observed flood levels. Calibration parameters could include:

- Manning's roughness values for the channel and floodplain
- friction slope associated with the downstream normal depth boundary condition
- ineffective flow areas
- expansion and contraction coefficients

For this study, channel roughness was the main calibration parameter. NHC's general calibration approach involved adjusting Manning's roughness values to ensure computed water levels closely matched observed HWMs during the selected high flow calibration event (2023 flood event). These roughness adjustments were made on a reach-averaged basis through comparison of computed and observed HWMs. The observed HWMs for the 2023 flood calibration event are only available along the Embarras River study reach.

No calibration data were available for Bryan Creek. However, as the channel bed material for Bryan Creek was comparable to that for the Embarras River, the calibrated values for the Embarras River were adopted as roughness values for Bryan Creek. Given the similarities in channel bed formation confirmed during the site visit, this approach was considered appropriate. Nevertheless, in the absence of site-specific calibration, unique channel characteristics such as irregularity, cross sectional variability, obstructions, vegetation, and meanders, may not be fully captured in the adopted Manning's roughness values.

Note that overbank and floodplain roughness values were not adjusted during the model calibration process. NHC characterized roughness in the floodplain areas (model overbanks) using land cover type determined by ground observations, collected aerial drone videos, and visual inspection of aerial imagery.

The other model parameters mentioned in the list above were not adjusted for calibration purposes; values within plausible limits were selected to achieve reasonable results.

Roughness Calibration Challenges and Limitations

Roughness calibration is associated with the following challenges and limitations:

- accuracy of HWM elevations
- improper identification of HWMs
- uncertainties in estimates of instantaneous flood peak discharge for the calibration event

One of the main challenges in this study was estimating the instantaneous peak discharge for the 2023 flood event used for calibration. As noted earlier, no streamflow gauges exist on the Embarras River or Bryan Creek within the study reach, and no direct discharge measurements were available for this event. NHC estimated the peak discharge (as described in the section below) using culvert hydraulics, based on the HWM observed at the upstream end of the Township Road 492A culvert, and then compared the results to regional hydrologic estimates. It is believed that the culvert hydraulics are well-defined and that using the observed HWM in conjunction with the culvert hydraulics provides a reasonable estimate of the 2023 flood peak discharge. Regional hydrology is considered to have greater uncertainty compared to the culvert hydraulics. However, since the discharge was not measured, the estimated 2023 flood peak remains subject to some uncertainty. As a result, the final roughness values were selected based on calibration outcomes but also validated through literature and other references to ensure appropriate channel Manning's roughness value was adopted.

2023 Flood Peak Estimation

The June 2023 flood was a significant event in the study region, with the peak flow occurring on 20 June 2023. In response to this event, EPA surveyed HWMs along the Embarras River study reach on 26 and 27 June 2023. The June 2023 flood was selected as the only calibration event for hydraulic modelling, but no flow measurements were available. To address this gap, the 2023 flood peak was estimated at Township Road 492A culvert located on Embarras River below Bryan Creek. The flow was estimated by adjusting the culvert discharge until the computed flood level from the hydraulic model agreed well with the surveyed HWM upstream of the culvert.

The Township Road 492A culvert location is ideal for estimating the flood peak, as the Embarras River sub-reach upstream of the culvert lies within a backwater zone dominated by the culvert capacity. In this zone, flood levels are not sensitive to channel roughness but are instead governed by discharge and other culvert specific parameters such as material, size, shape, and entrance and exit loss coefficients. The Township Road 492A culvert is a single barrel, 4.5 m diameter circular corrugated steel pipe (CSP) projecting from the embankment fill. All culvert parameters relevant to hydraulic computations are well established based on the literature. As a result, discharge was the primary unknown needed to simulate the observed HWM upstream of the culvert.

A range of discharges were tested to identify the best agreement between the simulated water level and the observed HWM. The closest flood frequency return period estimate was used for convenience. This approach is considered appropriate accounting the limitations and challenges in the calibration process with limited data. A 50-year return period flow, estimated as 77.2 m^3/s from the open water hydrology assessment (**Appendix D**), provided the best agreement with the HWM surveyed upstream of the culvert. The difference between the simulated water level (1093.82 m) and the observed HWM (1093.63 m) is approximately 0.19 m. It is important to note that the HWM was recorded at the upstream slope of the Township Road 492A culvert, while the simulated flood level corresponds to a location farther upstream at cross section XS-31 (RS

4,579). If the HWM had been collected at the same location as the simulated cross section, it would likely have been slightly higher, resulting in closer agreement. Therefore, adopting the 2023 flood peak corresponding as a 50-year return period for Embarras River below Bryan Creek is considered appropriate.

Using the estimated 50-year return period and the flood frequency curves developed with the P3 distribution for the Embarras River study reaches (as shown in Figure 4.3), the peak instantaneous discharge was determined to be 60.1 m^3/s for Embarras River above Bryan Creek and 77.2 m^3/s for Embarras River below Bryan Creek. The channel roughness values required to match the simulated flood levels with the observed HWMs using these discharges are well supported by reference values available in the literature (more discussion is provided in Section 4.3.4).

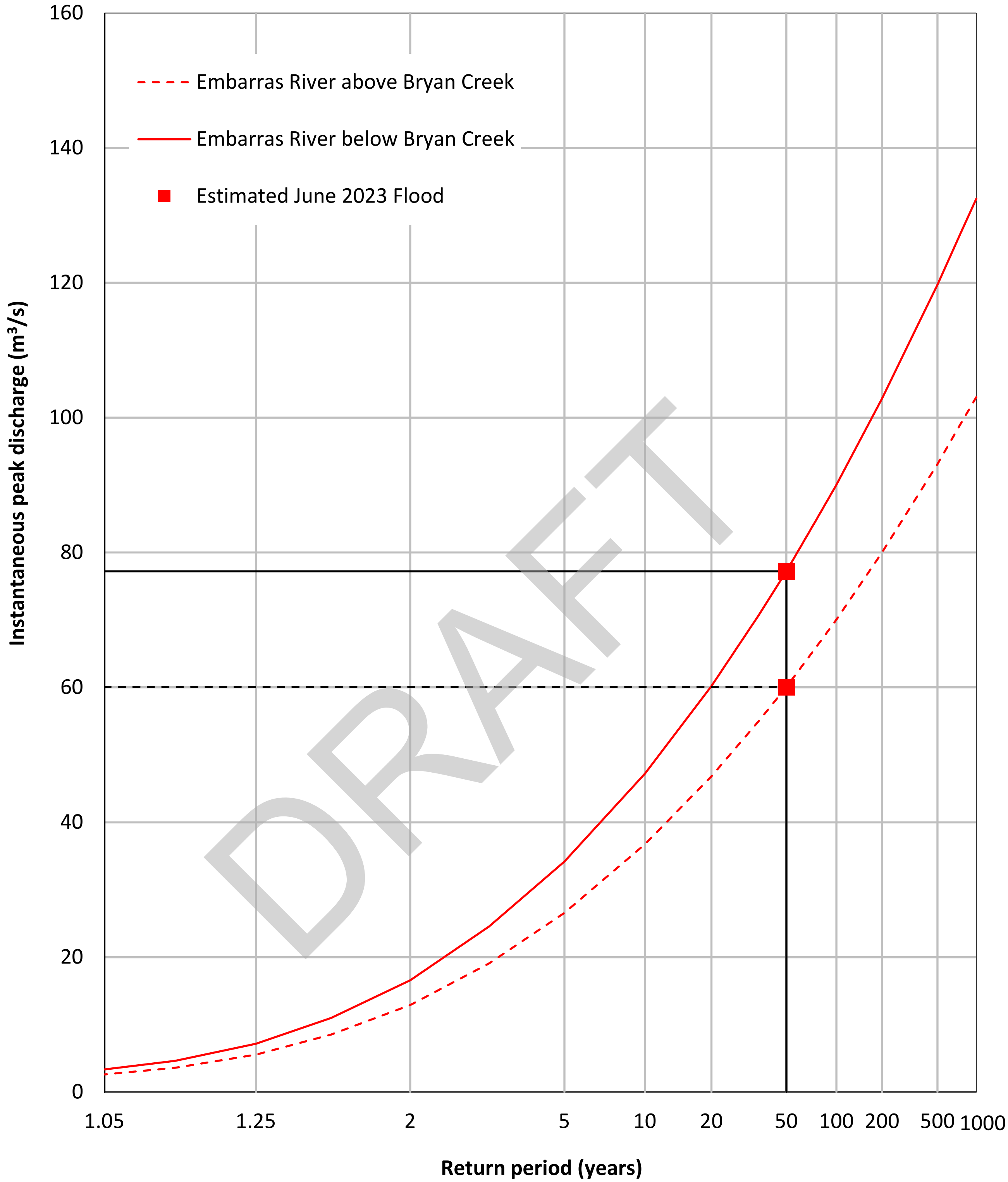
To provide additional context and comparison, the estimated peak discharge for the June 2023 flood based on regional hydrology was 54 m^3/s for the Embarras River above Bryan Creek and 67 m^3/s for the reach below Bryan Creek (refer to **Appendix D**). These values correspond to approximately a 35-year return period, which appears low, as matching the observed HWMs at these flow rates would require the use of relatively high channel roughness values, which would not be consistent with those found in the literature.

NHC also analyzed gauge data from the Embarras River near Weald (WSC Station 07AF014) and determined that the return period for the 2023 flood is approximately 69 years. It is important to note that the 2023 flood resulted from rainfall concentrated primarily in the central area of the McLeod river basin (near Edson, AB). Therefore, it is expected that the lower Embarras River would experience more severe flood than the upper Embarras River, where this project is situated.

High Flow Calibration

NHC selected the 20 June 2023 flood as the calibration event because it is the only flood within the study area with reliable HWMs. High flow calibration was conducted only for Embarras River, as no HWM data is available for Bryan Creek. The discharge for this event was estimated as described in the above section.

The calibration results are illustrated by comparing the computed water surface elevations (WSEs) with the observed HWM elevations. Figure 4.4 shows a comparison between the computed water surface profile and the observed HWM elevations for the calibration event (June 2023 flood), Table 4.3 summarizes the comparison. For the June 2023 flood event, the average difference between computed and observed HWM elevations was 0.01 m, while the absolute difference was 0.27 m; the largest positive difference was 0.54 m, and largest negative difference was -0.40 m.



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

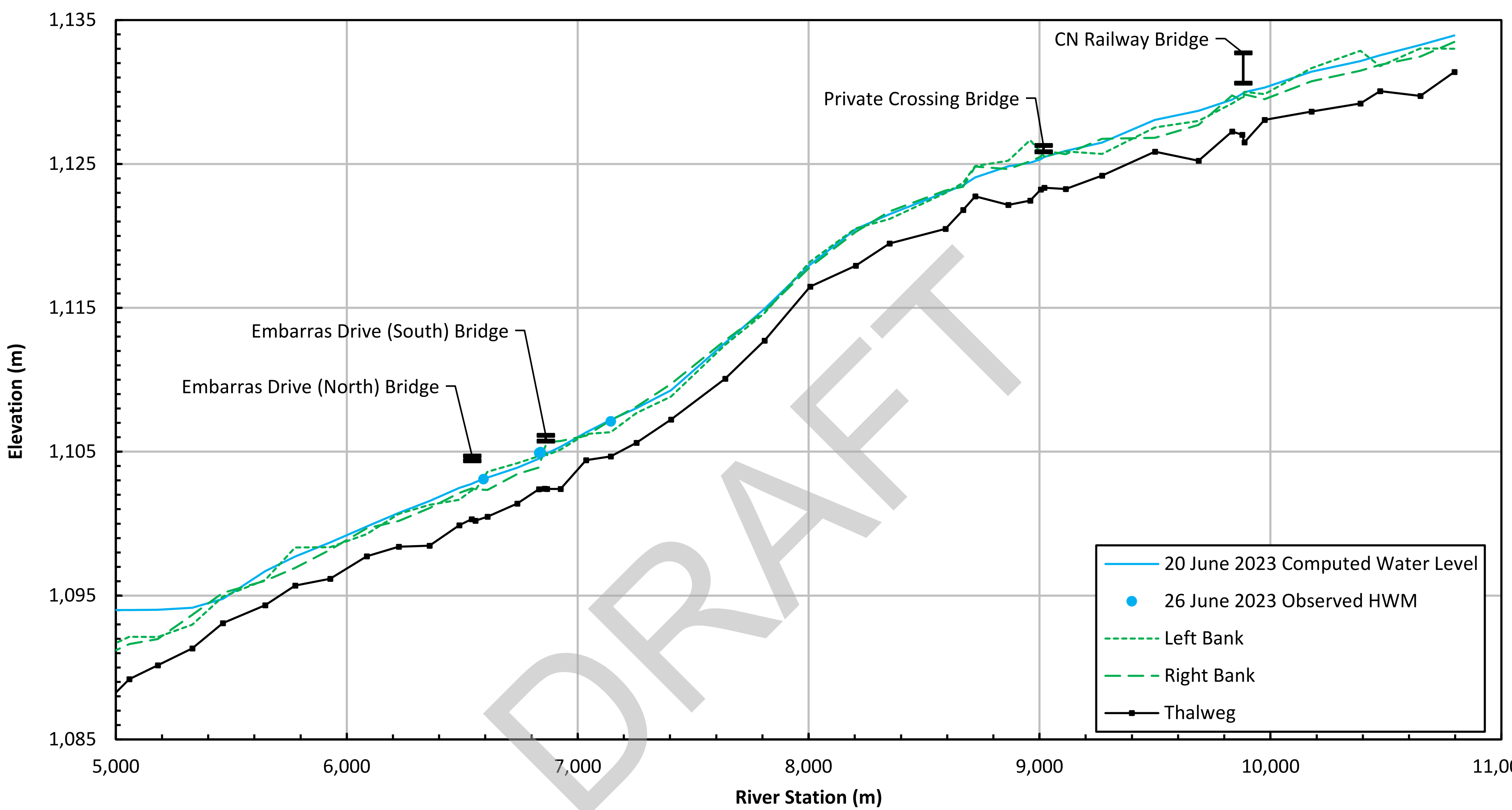
Job: 1009252 | *Date: 29-JULY-2025*

ROBB FLOOD STUDY

ADOPTED FLOOD FREQUENCY CURVES FOR EMBARRAS RIVER

FIGURE 4.3

Classification: Public



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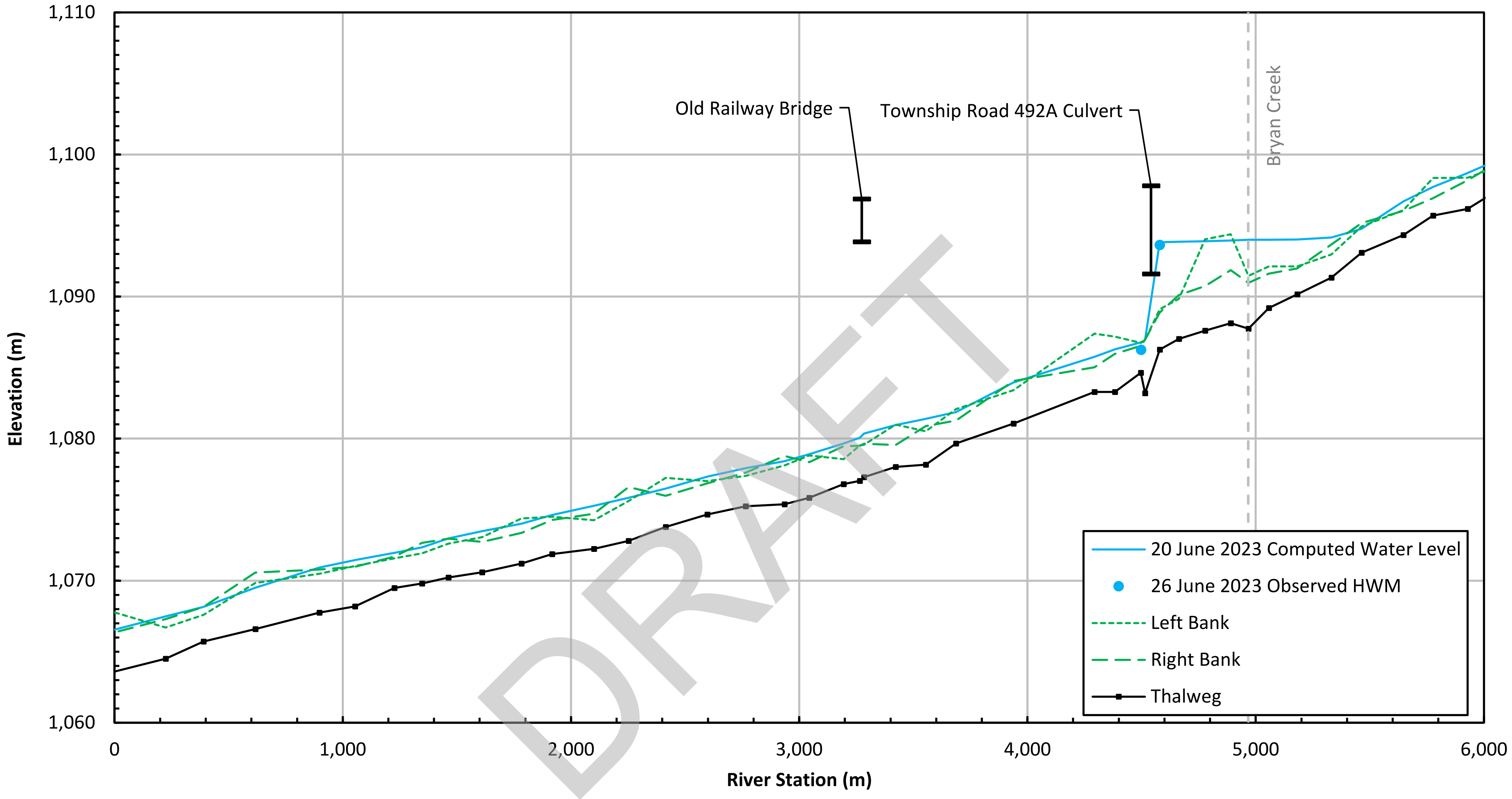
Job: 1009252 | *Date: 28-AUG-2025*

ROBB FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS FOR EMBARRAS RIVER – JUNE 2023 FLOOD EVENT (1/2)

FIGURE 4.4



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
nhc	Coordinate System: Units: As Shown	**COMPUTED VS OBSERVED WATER LEVELS FOR EMBARRAS RIVER – JUNE 2023 FLOOD EVENT (2/2)**
	Job: 1009252 — *Date: 28-AUG-2025*	FIGURE 4.4

Table 4.3 High flow calibration results for June 2023 flood

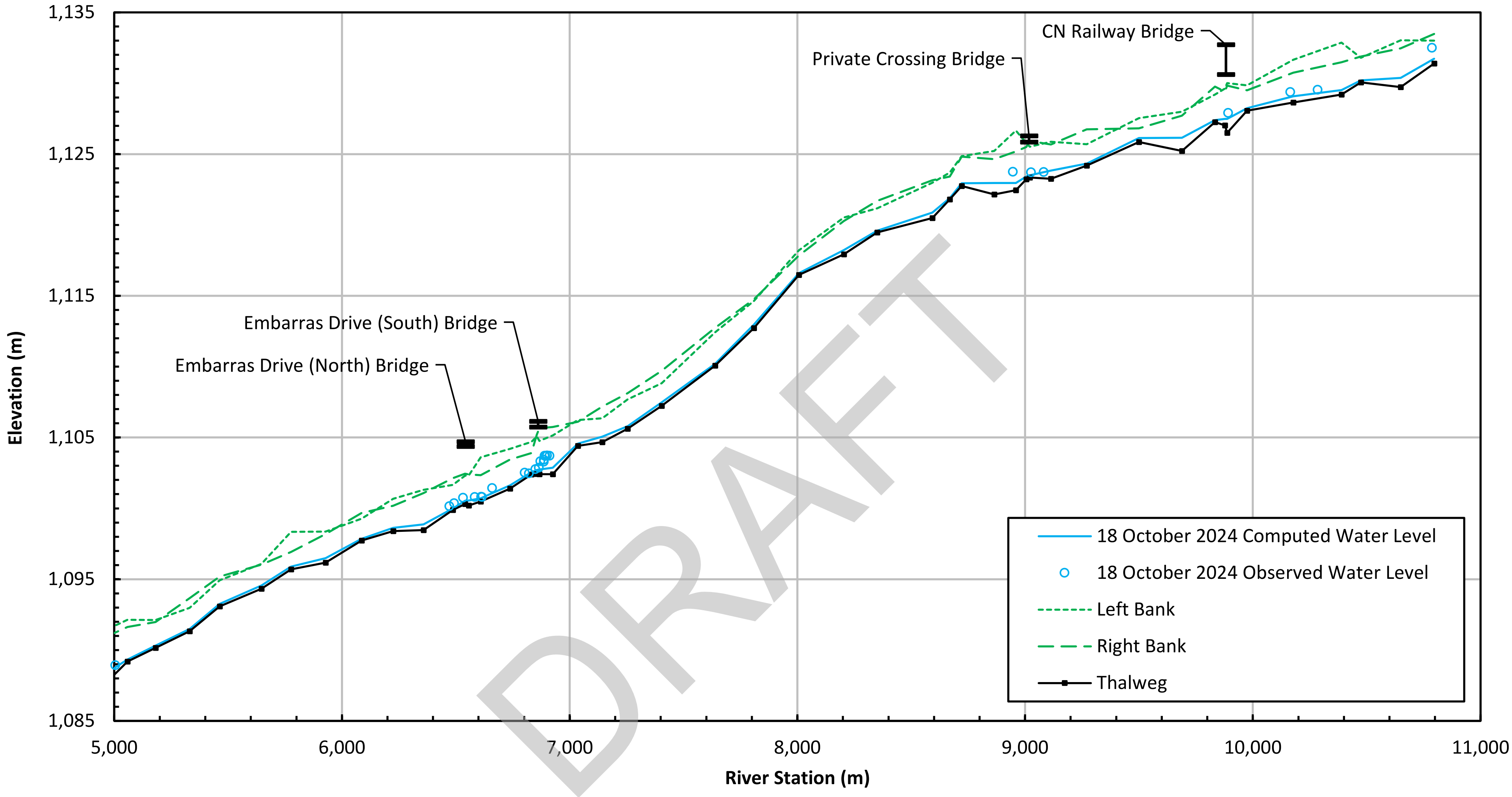
River	Reach	River Station (m)	HWM ID	Observed HWM Elevation (m)	Estimated Discharge (m^3/s)	Computed WS Elevation (m)	Computed minus Observed (m)
Embarras River	Above Bryan Creek	7,143	Emb-Robb-3 (HWM1)	1107.102	60.1	1107.210	0.108
		6,838	Emb-Robb-2 (HWM1)	1104.963	60.1	1104.573	-0.390
		6,833	Emb-Robb-2 (HWM2)	1104.926	60.1	1104.529	-0.397
		6,592	Emb-Robb-1 (HWM1)	1103.095	60.1	1103.099	0.004
	Below Bryan Creek	4,579	Emb-Robb-4 (HWM1)	1093.630	77.2	1093.820	0.190
		4, 497	Emb-Robb-5 (HWM1)	1086.253	77.2	1086.788	0.535

While high flow calibration impacts the selection of Manning's roughness values, the limited availability of calibration data and uncertainties with the 2023 peak flow estimation makes it crucial to ensure that the chosen values align with those documented in the literature and fall within the range used in previous studies for similar streams. Additional details on channel roughness selection are provided in Section 4.3.4.

Low Flow Validation

Flow measurements and corresponding water levels from the 18 October 2024 survey were used to validate the HEC-RAS model, with measurements taken for Embarras River and Bryan Creek on the same day. The measured discharge on Embarras River was 0.22 m^3/s above Bryan Creek, 0.26 m^3/s below Bryan Creek, and 0.04 m^3/s on Bryan Creek. For context, the 2-year flood flow estimated from hydrology analysis for Embarras River is 12.9 m^3/s above Bryan Creek, 16.6 m^3/s below Bryan Creek, and 3.5 m^3/s on Bryan Creek. Thus, the low flow validation is not applicable to inform selecting the parameters including channel roughness for the flood model.

The validation results are shown by comparing the computed WSEs with the observed water levels in Figure 4.5 for Embarras River and in Figure 4.6 for Bryan Creek. For the 2024 NHC survey period, computed water levels were on average 0.40 m below the observed levels. The results from low flow validation are reasonable and not unexpected. Low flow roughness values are typically higher than high flow roughness values due to the greater contribution of bed roughness and channel control during low flow conditions.



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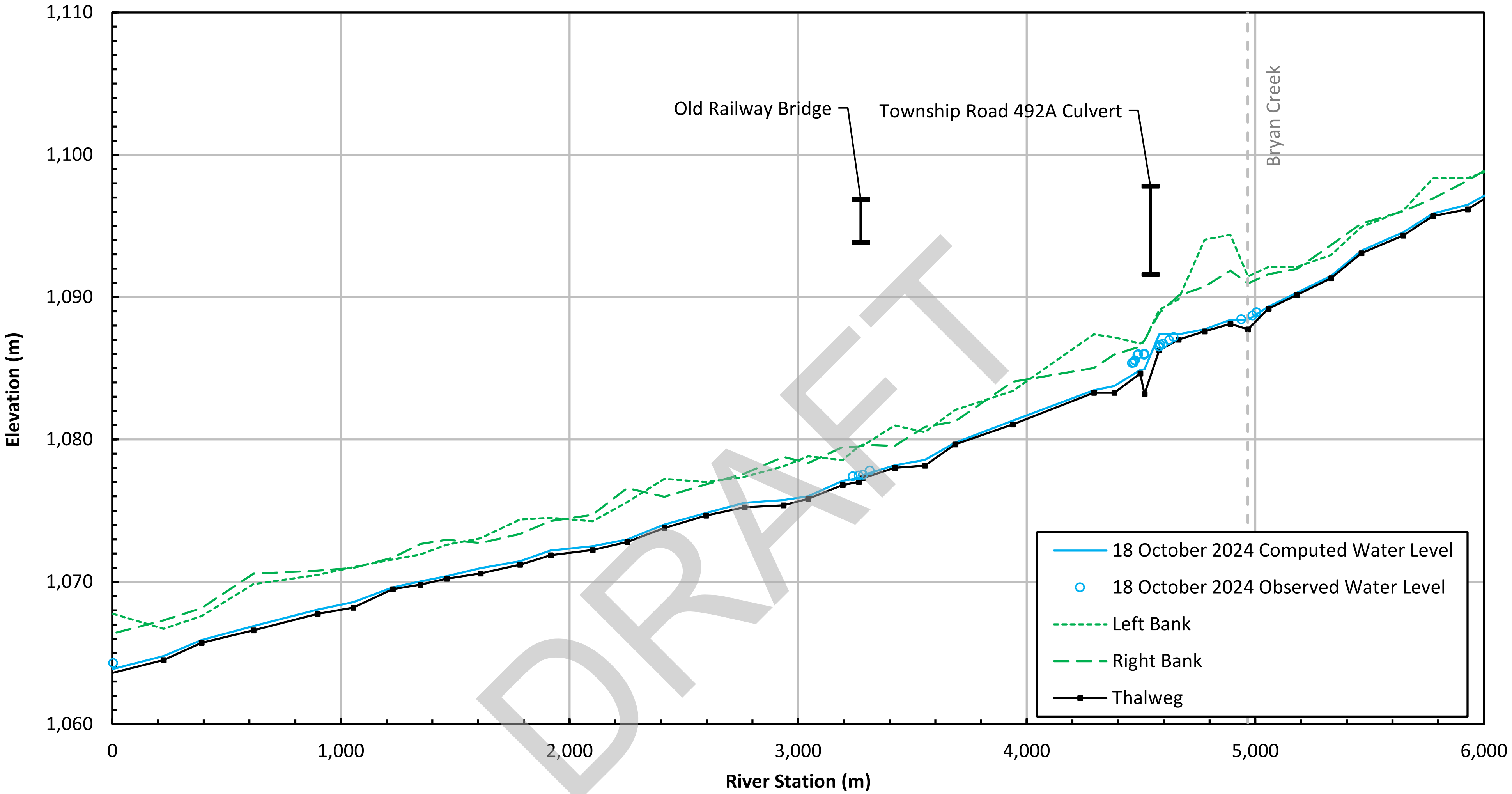
Date: 28-AUG-2025

ROBB FLOOD STUDY

COMPUTED VS OBSERVED LOW FLOW WATER LEVELS FOR EMBARRAS RIVER – 18 OCTOBER 2024 (1/2)

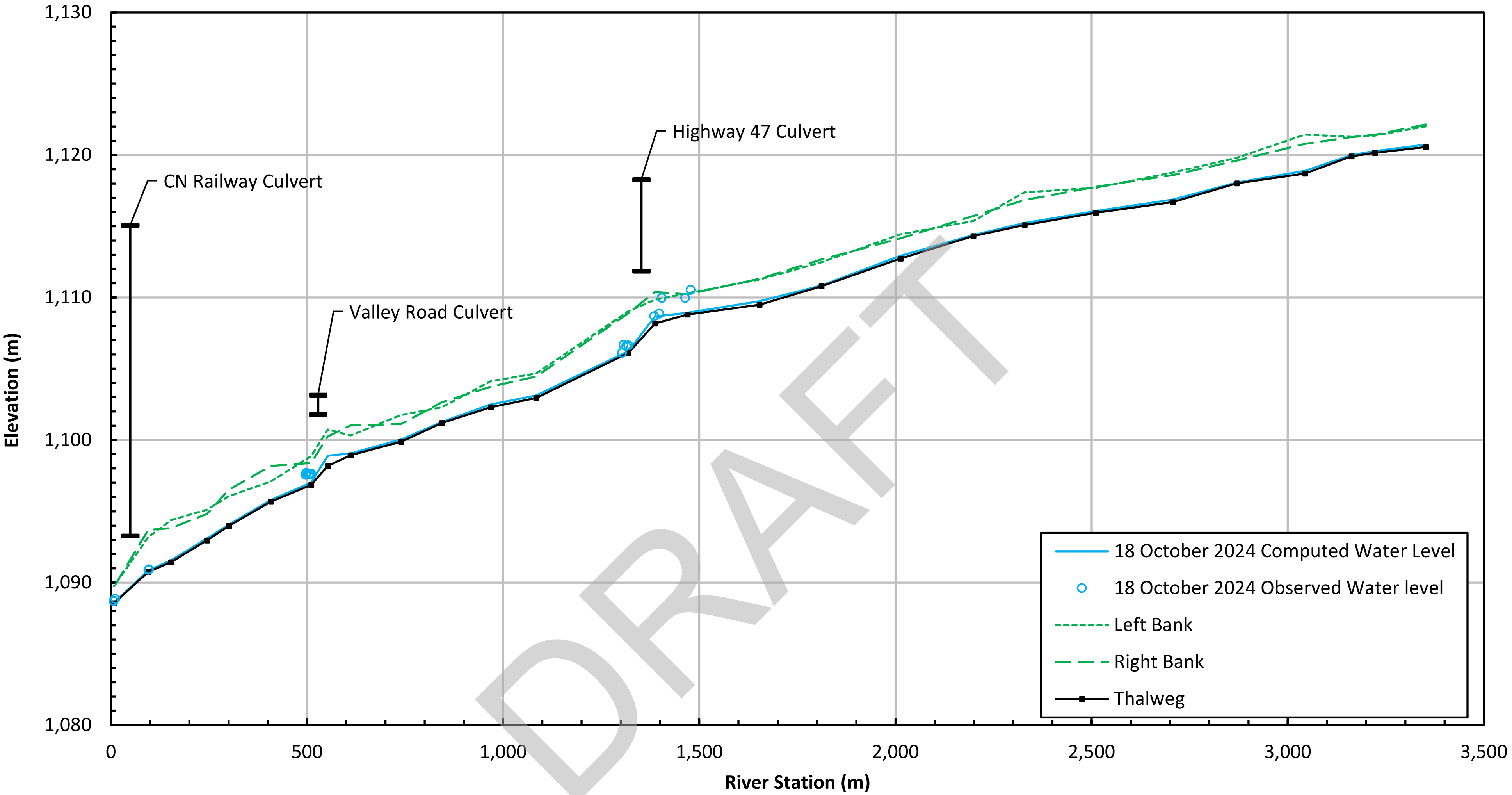
FIGURE 4.5

Classification: Public



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
nhc	Coordinate System: Units: As Shown	**COMPUTED VS OBSERVED LOW FLOW WATER LEVELS FOR EMBARRAS RIVER – 18 OCTOBER 2024 (2/2)**
	Job: 1009252 / *Date: 28-AUG-2025*	FIGURE 4.5

Classification: Public



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

COMPUTED VS OBSERVED LOW FLOW WATER LEVELS FOR BRYAN CREEK – 18 OCTOBER 2024

FIGURE 4.6

4.3.4 Model Parameters and Options

The following sections describe the key parameters and options adopted in the HEC-RAS model. These include Manning's roughness values for channel and overbank areas; contraction and expansion loss coefficients; ineffective areas; and roadway weir coefficient.

Manning's Roughness

Manning's roughness is used to account for an array of energy losses that may vary with respect to discharge. A minimum of three (one channel and two overbank) roughness values were used within each cross section.

Channel Roughness

NHC calibrated channel roughness along the Embarras River study reaches using the June 2023 flood event. Calibration for Bryan Creek was not possible due to the absence of HWM data. However, both the Embarras River and Bryan Creek have similar channel bed materials (primarily gravel and cobbles, with occasional large boulders) suggesting a consistent channel roughness value can be applied across all study reaches. A Manning's roughness value of 0.064 was selected for channel, as it provided the best fit between simulated water levels and the 2023 HWM data. This value also aligns well with reference values from the literatures. A summary of the selected value and its comparison with literatures and similar study is provided in Table 4.4.

Table 4.4 Selected Manning's roughness values for main channel

River	Reach	River Station	Channel Bed Material	Selected Manning's Roughness	Literature Suggested Manning's Roughness
Embarras River	Above Bryan Creek	4,968-10,796	Gravel and cobbles, with occasional large boulders	0.064	0.04-0.07 (Chow, 1959) 0.051-0.075 (Barnes, 1967) 0.065 (Arcement and Schneider, 1989)
	Below Bryan Creek	0-4,890			
Bryan Creek	Main	0-3,352			

The Table 4.4 above summarizes the comparison of the selected channel Manning's roughness value with three key literature sources. Among these, Chow (1959) recommended a typical roughness value of 0.05 for gravel and cobble bed rivers, noting that values can reach up to 0.07 in the presence of very large boulders. Given that the Embarras River and Bryan Creek contain occasional boulders, the channel roughness for this study is reasonably expected to be below 0.07. Barnes (1967) provided photographic documentation of natural channels in the U.S., allowing for visual comparison. By comparing our site photos with those in Barnes (1966), the estimated roughness range for the study area falls between 0.051 and 0.075. Additionally, the Arcement and Schneide (1989) guidance for estimating Manning's roughness accounts for factors such as channel irregularity, cross section variation, obstructions, vegetation, and meandering. Applying this method, NHC estimated a roughness value of approximately 0.065. Overall, the selected value of 0.064 is consistent with the literature and falls toward the upper end of the expected range.

Overbank Roughness

NHC selected Manning's roughness values for the various overbank land cover and vegetation types based on values from available literature (Chow 1959; Arcement and Schneider 1989). Roughness values were assigned according to the dominant land cover within the study area, informed by aerial photographs, field observations, and drone video analysis. Table 4.5 summarizes the selected overbank roughness values for each land cover type. These values are consistent with NHC's recent experience conducting flood studies in Alberta.

Table 4.5 Selected Manning's roughness values for overbank areas

Dominant Land Cover Type	Description	Selected Manning's Roughness	Literature Manning's Roughness Range
Urban/Built Area	Development within the wetted width of the design flood with buildings, yards, parks, and transportation corridors	0.085	0.060-0.14
Trees	Dense, willows, straight tree covered area	0.15	0.11-0.20

Expansion and Contraction Coefficients

To account for the effect of flow contraction and expansion losses on the energy balance between successive cross sections, HEC-RAS multiplies the absolute difference in velocity head by a coefficient. The default values of 0.1 and 0.3 (for expansion and contraction coefficients) were utilized throughout the majority of the model domain. For cross sections located at bridge and culvert crossings, expansion and contraction coefficients were increased to the recommended values of 0.3 and 0.5, respectively. In addition, a higher expansion coefficient of 1.0 was applied at specific locations, primarily within backwater transition zones, to account for increased energy losses and to simulate more reasonable water surface profiles for all thirteen frequency floods and ensure successive profiles nest with respect to one another. Adjustments were made under the assumption that the surveyed geometry may not fully capture all actual energy losses occurring throughout the reach. Given the limitations of 1D modelling, higher energy losses were sometimes required to generate consistent and realistic flood frequency profiles.

Weir Coefficient

HEC-RAS uses a broad crested weir formulation to simulate flow overtopping hydraulic structures. Typical discharge coefficients range between 1.45 and 1.80, with larger values generating less backwater. Flow overtopping a bridge deck is not ideally represented by a broad crested weir, and it is generally recommended that lower values be used when an increased resistance to flow from obstructions such as bridge railings, curbs, and debris (FHA, 2012) is anticipated. The bridges and road embankments within the study area could cause moderate resistance to flow, thus a weir coefficient of 1.6 was deemed appropriate for all hydraulic structure embankments in this study.

Upstream Boundary Condition

A specified discharge is required at the upstream end of each modelled reach. This study includes three modelled reaches within the study area, with flow input locations summarized in Table 4.6. The discharges for various return periods estimated at the flood frequency sites referenced in the table below were used as the upstream boundary condition.

Table 4.6 Summary of flow input locations

River	Reach	River Station (m)	Flood Frequency Site Name
Embarras River	Above Bryan Creek	10,796	Embarras River above Bryan Creek
	Below Bryan Creek	4,890	Embarras River at downstream study boundary
Bryan Creek	Main	3,352	Bryan Creek at the mouth

Downstream Boundary Condition

At the downstream boundary of the Embarras River, a normal depth water level approximation was applied as the boundary condition. The slope used for calculating normal depth was set to 0.005 m/m representing the estimated energy grade line slope near the downstream boundary. This slope was determined using the surveyed thalweg on the downstream study boundary and verified based on water surface slope derived from the DTM data.

Ineffective Flow Areas

Ineffective flow areas were specified at cross sections in the HEC-RAS model based on a review of the local terrain and floodplain features both at and between cross sections. The preliminary 2D model was also used to inform the ineffective flow areas. Ineffective flow areas can be specified within portions of cross sections where water is expected to pond, and where the velocity of that water, in the downstream direction, is 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. The configuration of permanent and non-permanent ineffective flow areas was specified depending on site-specific circumstances and engineering judgement.

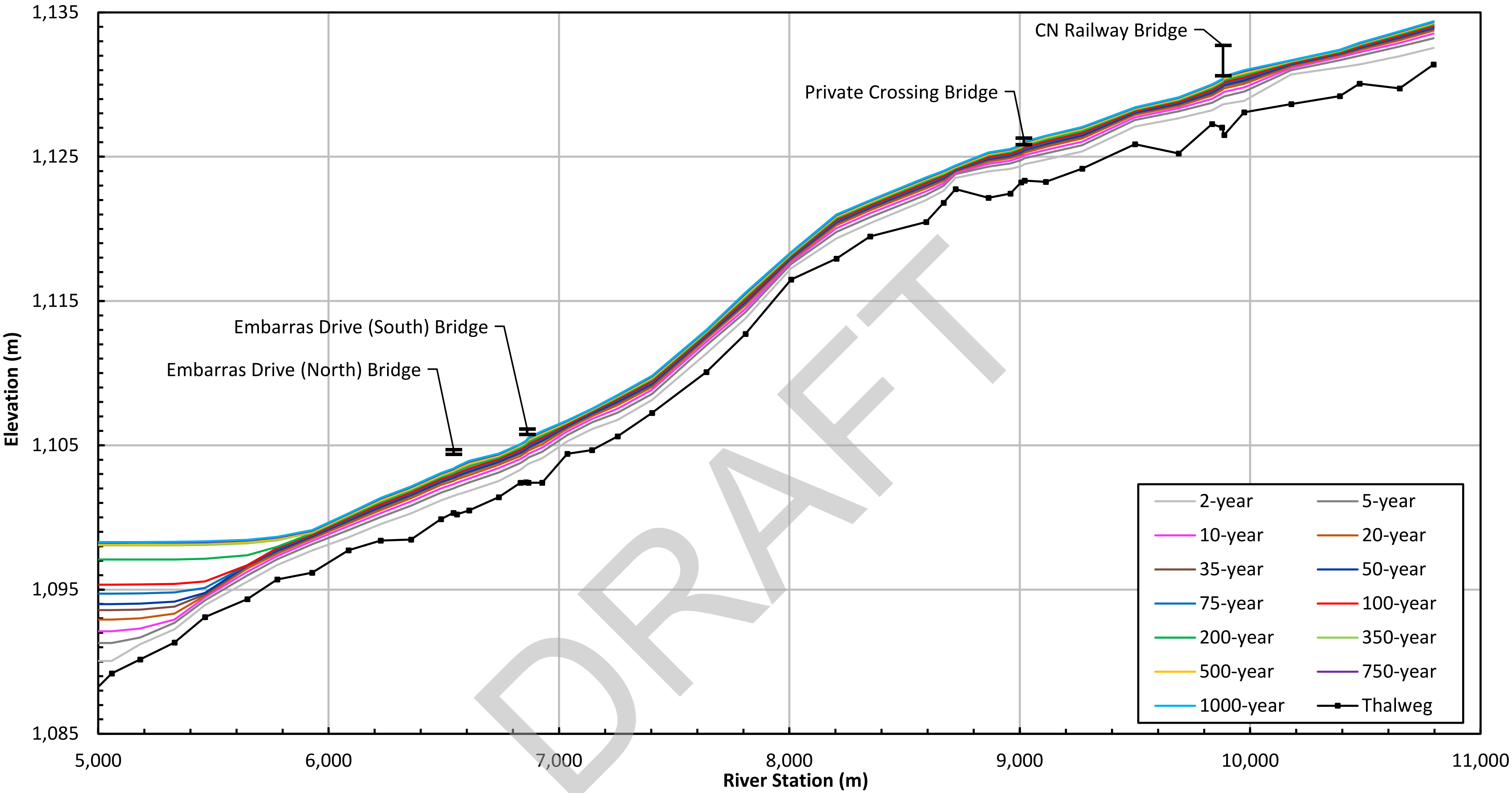
The general principles for determining ineffective flow areas were as follows:

- Non-permanent ineffective flow areas were used to “fill” local depressions on the floodplain that are obstructed by higher ground upstream or downstream. These areas were assumed to become effective once the water level exceeded the elevation of the adjacent ground.
- Permanent ineffective flow areas were used to permanently “fill” relic channels, tributary channels or excavated holes that would otherwise have incorrectly added flow area to the cross section.
- 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 and culverts 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.
- Ineffective flow areas behind railroad and highway embankments were assessed on an individual basis. Aerial imagery, LiDAR, and historic information were used to determine if there were indications of flow behind and/or above embankments. Areas behind and below the height of the embankment were modelled as effective flow only if there was no downstream obstruction or if there was an indication of flow moving in the downstream direction. Otherwise, permanent ineffective flow areas were set to the top of embankment elevation, allowing areas behind embankments (assumed permeable) to be shown as wet and isolated but not conveying flow. Areas above embankments generally conveyed flow once the embankment was overtopped, unless an upstream or downstream obstruction was present causing local ponding or dead zones with limited flow.

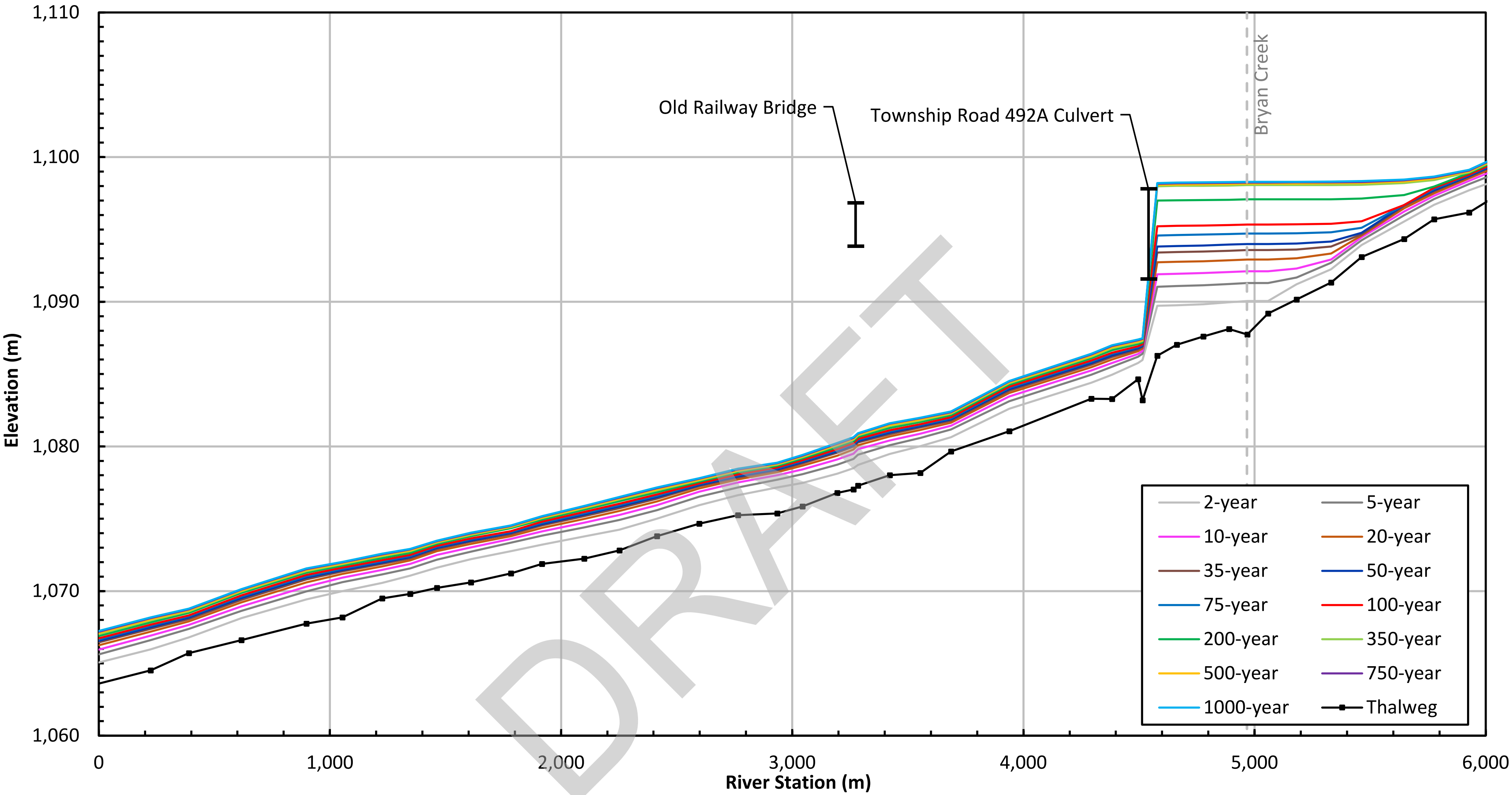
4.3.5 Flood Frequency Profiles

The hydraulic model was used to generate flood frequency profiles for the thirteen open water floods of varying magnitude ranging from 2-year to 1000-year return periods. The computed flood frequency water levels at each cross section on Embarras River and Bryan Creek are provided in **Appendix E**. The results are plotted in Figure 4.7 for Embarras River and Figure 4.8 for Bryan Creek.

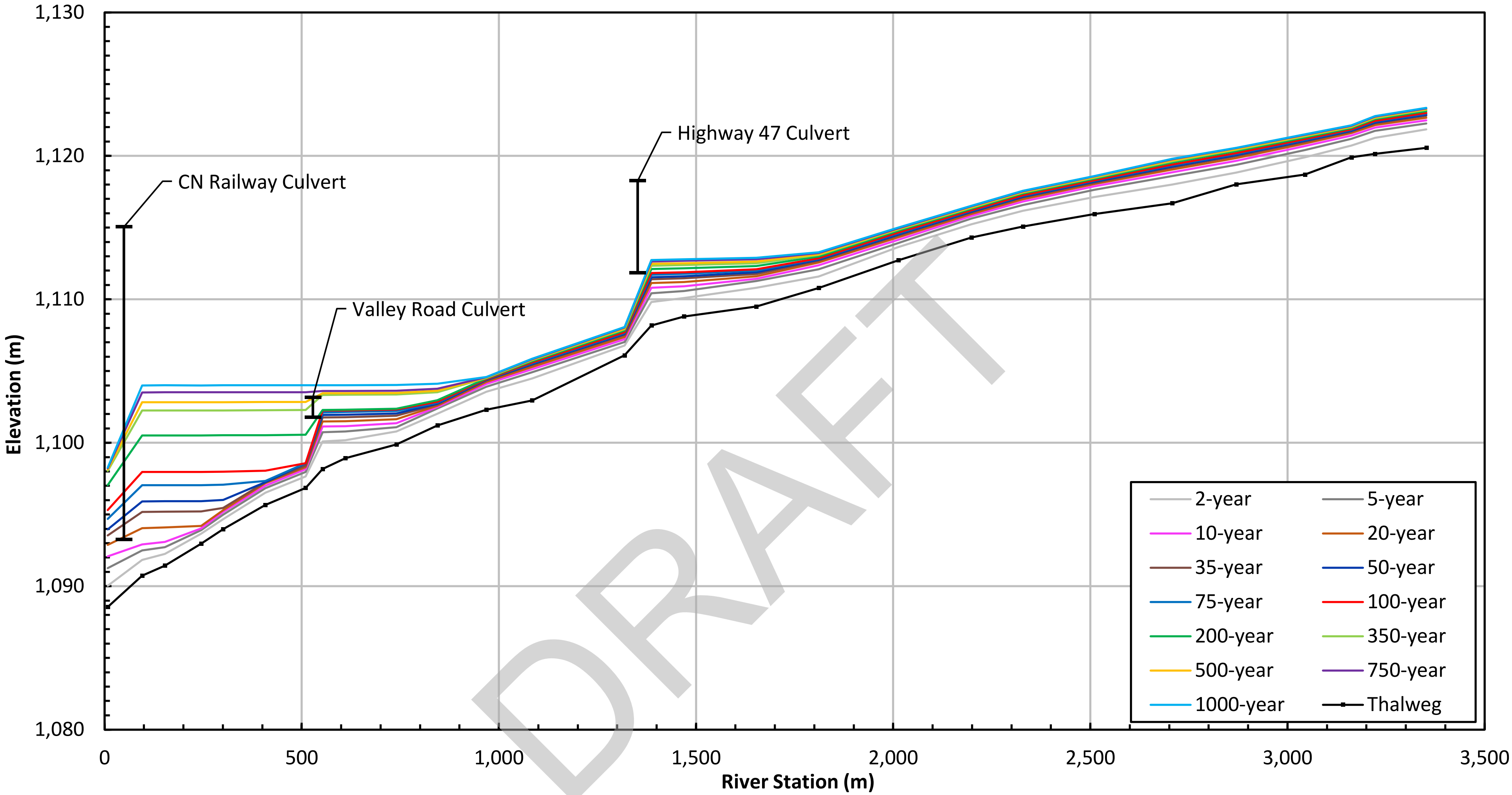
It should be noted that water levels along Embarras River were adjusted at XS-40 for the 100-year flood and on Bryan Creek at XS-89 for the 50-year flood to prevent crossing water surface profiles (i.e., a water level from a smaller flood event being higher than a water level from a larger flood event). This adjustment was made by reviewing the flood frequency profiles above and below each location, as well as the cross sections upstream and downstream, to determine an appropriate water level substitution. A footnote reference marked with an asterisk is included in **Appendix E** at every instance of this adjustment in the tables.



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
	Coordinate System: Units: As Shown	**EMBARRAS RIVER FLOOD FREQUENCY PROFILES (1/2)**
nhc	*Job: 1009252*	*Date: 28-AUG-2025*
		FIGURE 4.7



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
nhc	Coordinate System: Units: As Shown	**EMBARRAS RIVER FLOOD FREQUENCY PROFILES (2/2)**
	Job: 1009252 / *Date: 28-AUG-2025*	FIGURE 4.7



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
	Coordinate System: Units: As Shown	**BRYAN CREEK FLOOD FREQUENCY PROFILES**
nhc	*Job: 1009252* / *Date: 28-AUG-2025*	FIGURE 4.8

4.3.6 Model Sensitivity

A sensitivity analysis was conducted to assess the impact of key parameters on the hydraulic model results. Variations in boundary conditions (flood frequency estimates and downstream boundary conditions) and Manning's roughness values (channel and overbank) could impact computed water levels, which in turn affect flood depths and inundation widths. The sensitivity of computed water levels was analyzed to estimate the relative influence of each parameter. The 100-year flood was used as the baseline for this analysis. A summary of the sensitivity analysis results is provided in the following sections.

Note that sensitivity to the roadway weir coefficient at bridges and culverts was not evaluated, as the 100-year flood did not overtop any of the modelled roadway crossings.

Boundary Conditions

The boundary conditions for the HEC-RAS model include a discharge specified at the upstream boundary and a normal depth specified at the downstream boundary. Sensitivity analysis was conducted on both boundary conditions.

The discharges selected for the sensitivity analysis were the lower and upper 95% confidence limits of the 100-year flood peak (obtained from Table 3.1) and are summarized in Table 4.7 below. The table also includes the percentage change from the baseline discharge for both the lower and upper confidence limits.

Table 4.7 Flood frequency estimates used in sensitivity analysis

River	Reach	River Station (m)	100-year Flood Frequency Flow Estimates (m^3/s)		
			Baseline	Lower 95% Limit (change from Baseline)	Upper 95% Limit (change from Baseline)
Embarras River	Embarras River above Bryan Creek	10,796	70.0	61.0 (-13%)	82.8 (+18%)
	Embarras River below Bryan Creek	4,890	90.0	78.4 (-13%)	106.5 (+18%)
Embarras River	Bryan Creek	3,352	19.2	16.7 (-13%)	22.7 (+18%)

The computed water levels for these discharges are compared with the baseline model results in Figure 4.9 (for Embarras River) and Figure 4.10 (for Bryan Creek). A summary of the corresponding changes in water levels and inundation widths, relative to the 100-year baseline, is provided in Table 4.8. The results indicate that variations in discharge caused substantial changes in both water levels and inundation extents. On average, water levels were changed by up to 0.93 m, and inundation widths by up to 17 m. A maximum change of 3.36 m was observed in water level and 83 m in the inundation width. This significant variation was primarily attributed to the limited capacity of the Township Road 492A culvert. While discharge magnitude directly affects water levels and inundation widths, the effect is amplified when flow is constrained by limited culvert capacity, meaning even small changes in discharge can result in large changes in flood response under such conditions. However, this amplified effect was observed only in the backwater area influenced by the culvert's constriction.

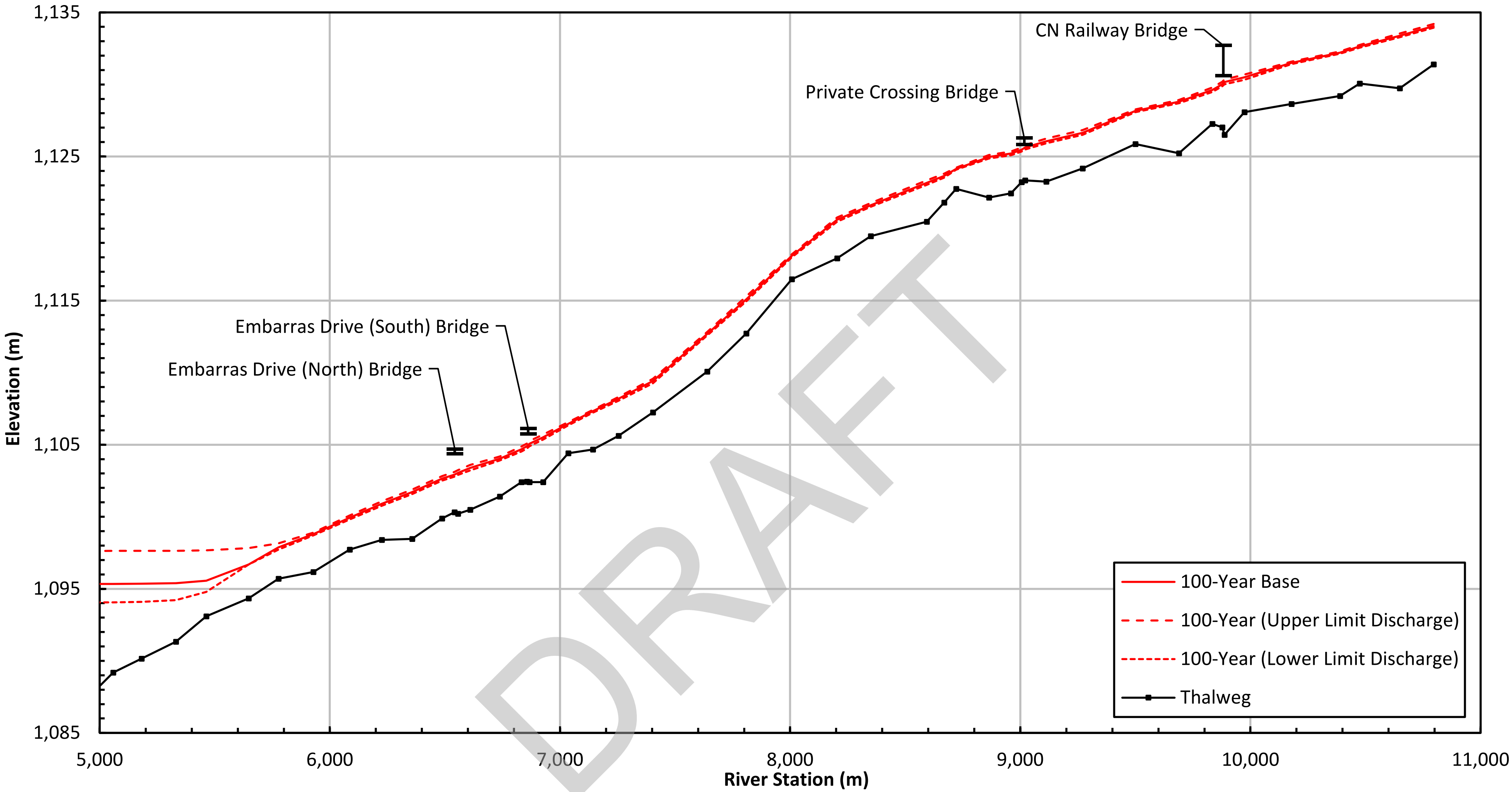
Table 4.8 Sensitivity analysis results to variation in 100-year flood frequency estimates

Parameter	River	Difference from Baseline Profile (m)			
		Lower 95% Limit		Upper 95% Limit	
		Maximum	Average	Maximum	Average
Water Level/Flood Depth	Embarras River	-1.32	-0.25	2.33	0.41
	Bryan Creek	-1.92	-0.47	3.36	0.93
Inundation Width	Embarras River	-73	-12	68	17
	Bryan Creek	-30	-6	83	11

The adopted downstream boundary condition was based on a normal depth approximation, where the water level was calculated by Manning's equation with a specified energy slope equal to 0.005 m/m. The calculated water level at most downstream cross section for the 100-year flood was 1066.73 m. The sensitivity analysis was performed for this parameter by adopting ±0.30 m as a plausible range of uncertainty.

The results showed no difference in computed water surface elevations and inundation widths from the baseline condition within the study limits. This confirmed that the downstream model boundary, about 1 km beyond the study limit, was far enough that it had no effect on the inundation mapping results. The variation of the sensitivity test profiles from the baseline are depicted in Figure 4.11 for Embarras River. No profile plot was presented for Bryan Creek as it is not sensitive to the change of downstream boundary conditions.

Detailed results of boundary conditions sensitivity analysis are provided in **Appendix F**.



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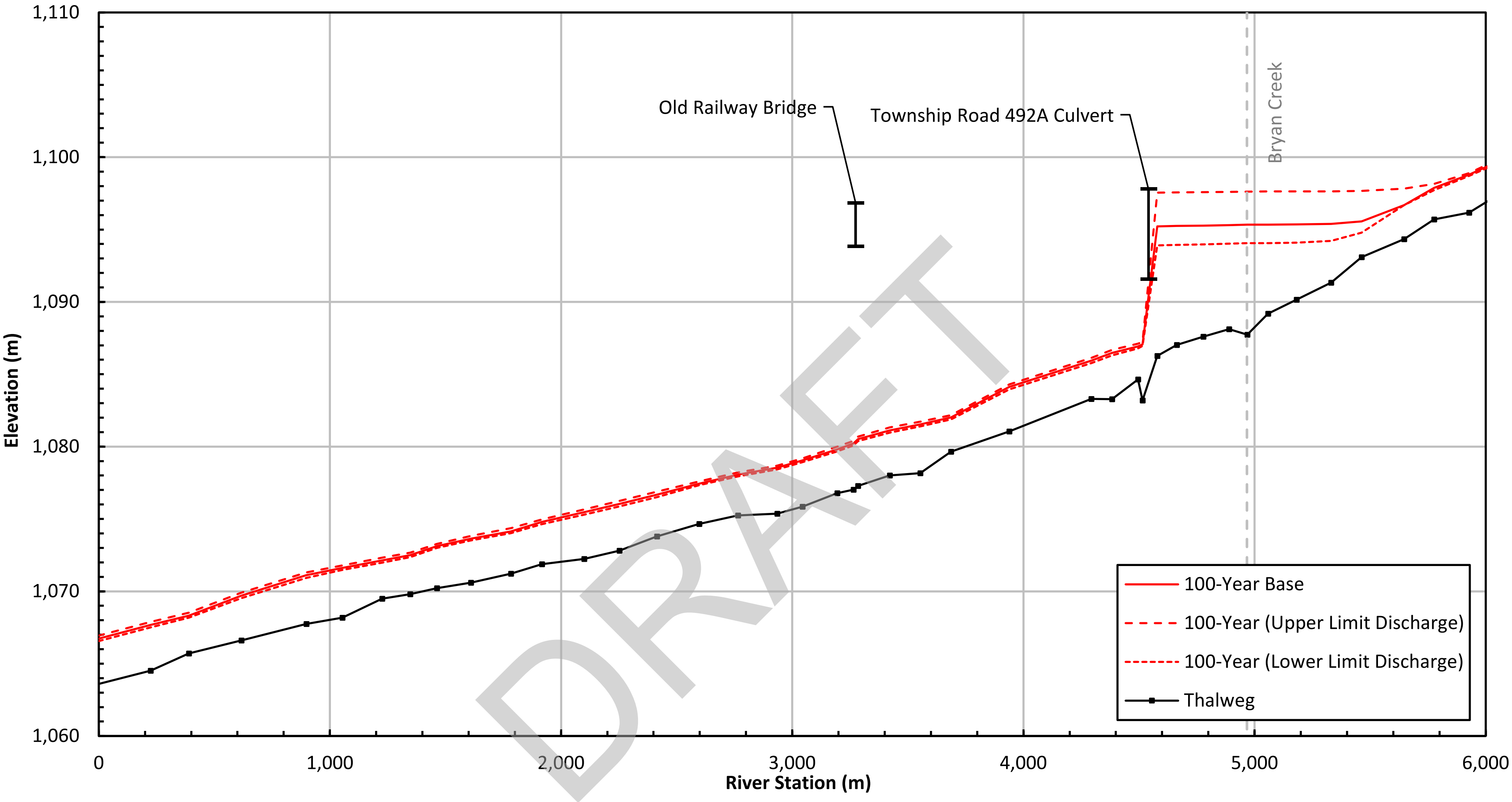
ROBB FLOOD STUDY

EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – UPSTREAM BOUNDARY DISCHARGE (1/2)

FIGURE 4.9



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Coordinate System:
Units: As Shown

Job: 1009252

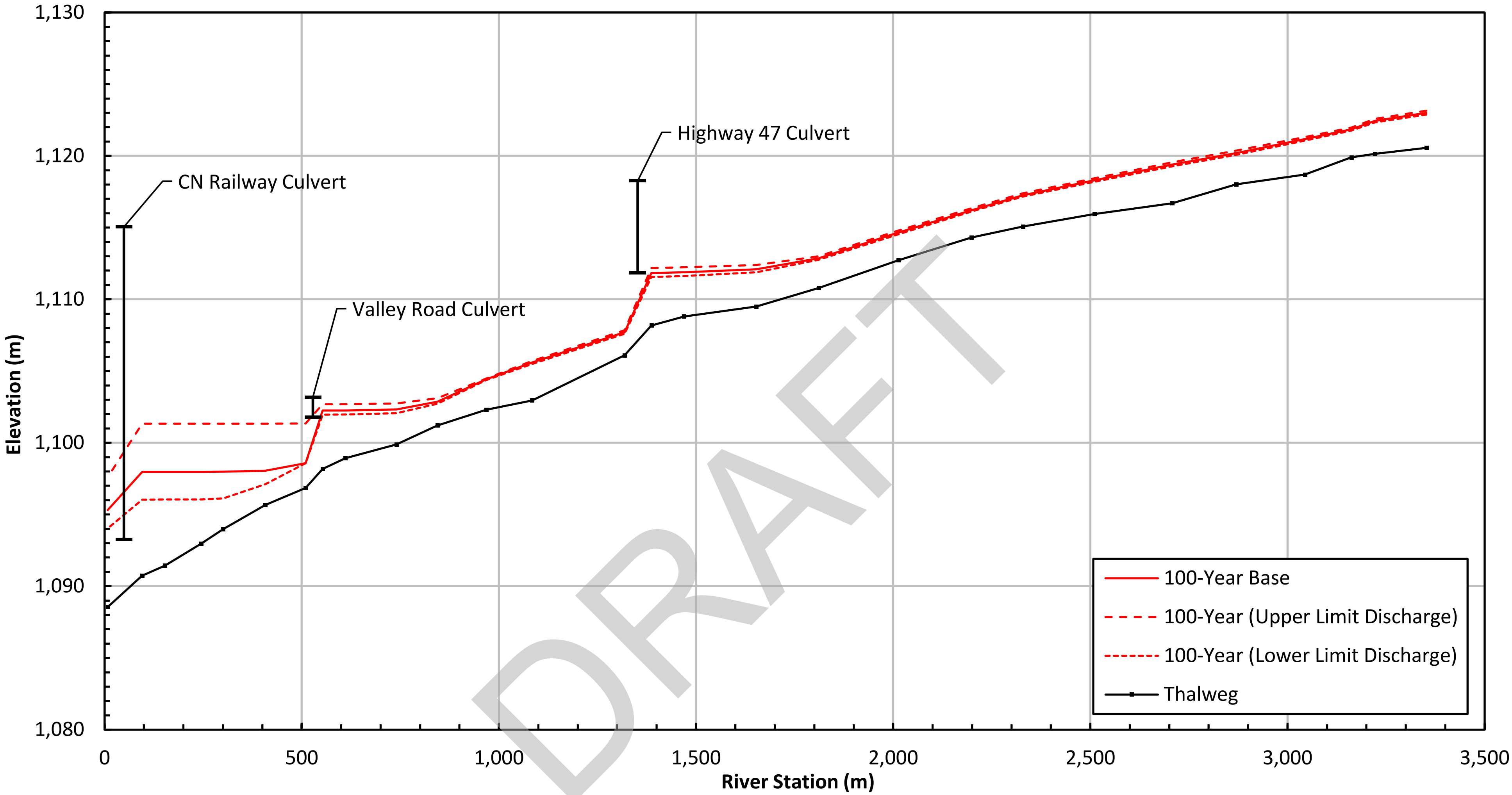
Date: 28-AUG-2025

ROBB FLOOD STUDY

EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – UPSTREAM BOUNDARY DISCHARGE (2/2)

FIGURE 4.9

Classification: Public



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

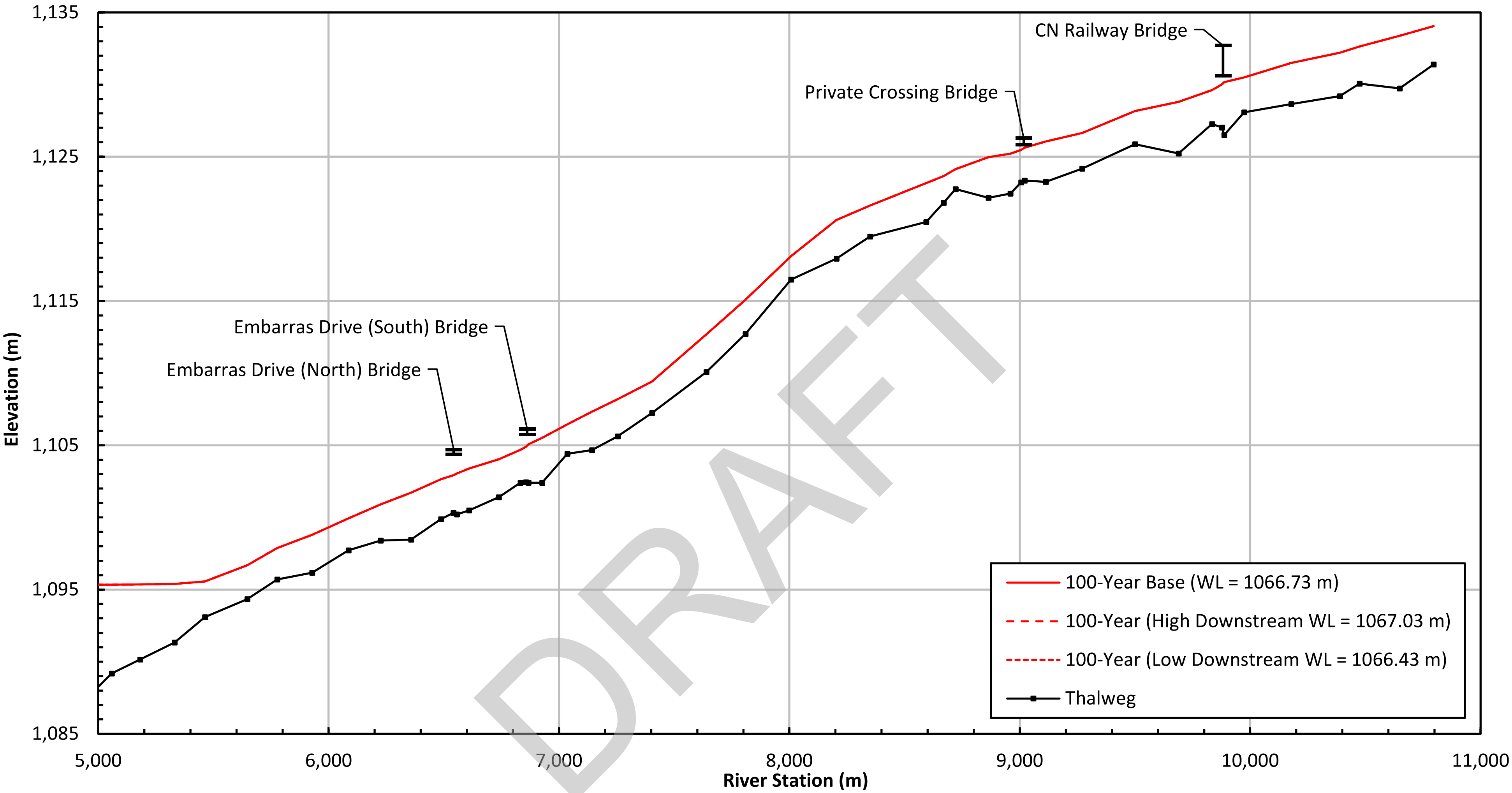
Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

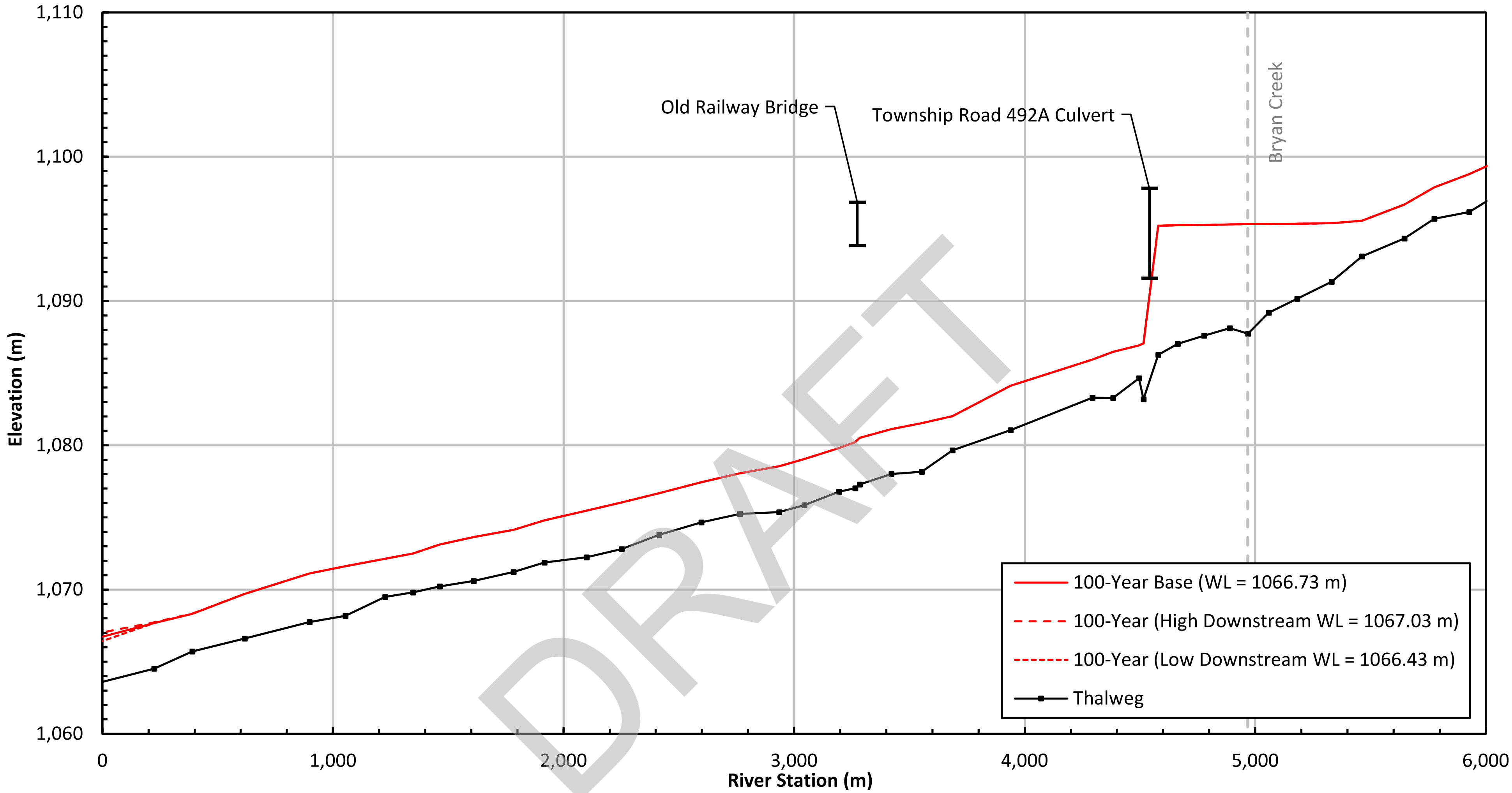
BRYAN CREEK SENSITIVITY ANALYSIS PROFILE – UPSTREAM BOUNDARY DISCHARGE

FIGURE 4.10



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
nhc	Coordinate System: Units: As Shown	**EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – DOWNSTREAM BOUNDARY WATER LEVEL (1/2)**
	Job: 1009252 | *Date: 28-AUG-2025*	FIGURE 4.11

Classification: Public



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Units: As Shown

Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – DOWNSTREAM BOUNDARY WATER LEVEL (2/2)

FIGURE 4.11

Manning's Roughness

The sensitivity of the model to Manning's roughness was evaluated, with channel roughness examined independently of overbank roughness. The sensitivity analysis was performed for all the modelled reaches, and the results are discussed below.

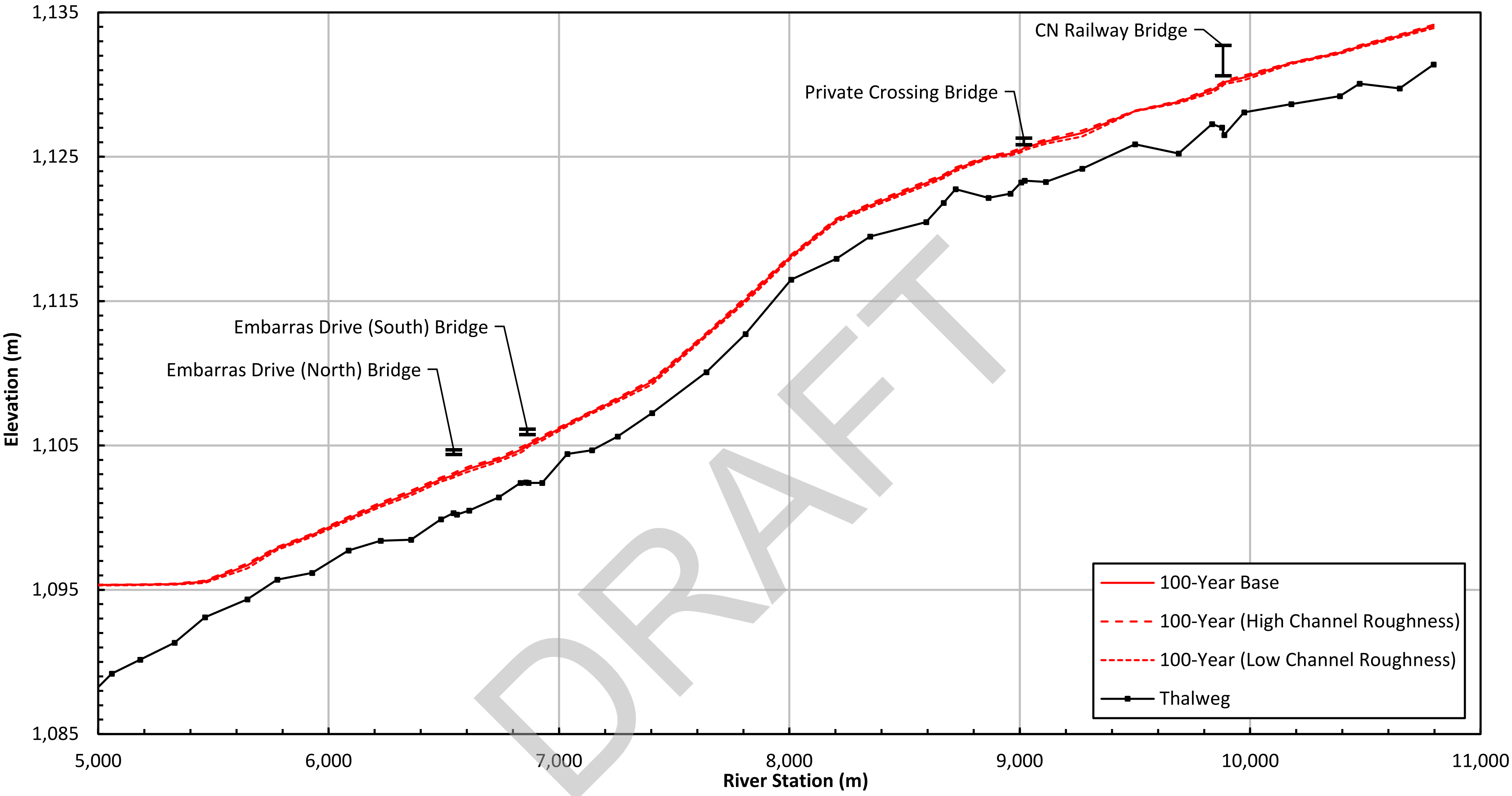
The sensitivity of computed 100-year flood levels to channel roughness was assessed using low and high roughness values for each of the modelled river reaches. The main channel Manning's roughness value of 0.064 (for both the Embarras River and Bryan Creek) was adjusted by ±15%. This equated to a lower roughness value of 0.054, and higher value of 0.074. This is believed to be a plausible range of channel roughness according to the literature reviewed.

Figure 4.12 (for Embarras River) and Figure 4.13 (for Bryan Creek) illustrate the differences between the channel roughness sensitivity test profiles and the 100-year baseline, and Table 4.9 summarizes the corresponding changes in water levels and inundation widths. On average, water levels varied by up to 0.14 m, and inundation widths by up to 10 m. The maximum changes observed were 0.24 m in water level and 57 m in inundation width.

Table 4.9 Sensitivity analysis results to variation in main channel roughness

Parameter	Reach	Difference from Baseline Profile (m)			
		Low Roughness (-15%)		High Roughness (+15%)	
		Maximum	Average	Maximum	Average
Water Level/Flood Depth	Embarras River	-0.24	-0.14	0.18	0.11
	Bryan Creek	-0.18	-0.08	0.16	0.07
Inundation Width	Embarras River	-51	-10	57	10
	Bryan Creek	-7	-2	11	2

Detailed results of main channel roughness sensitivity analysis are provided in **Appendix F.**



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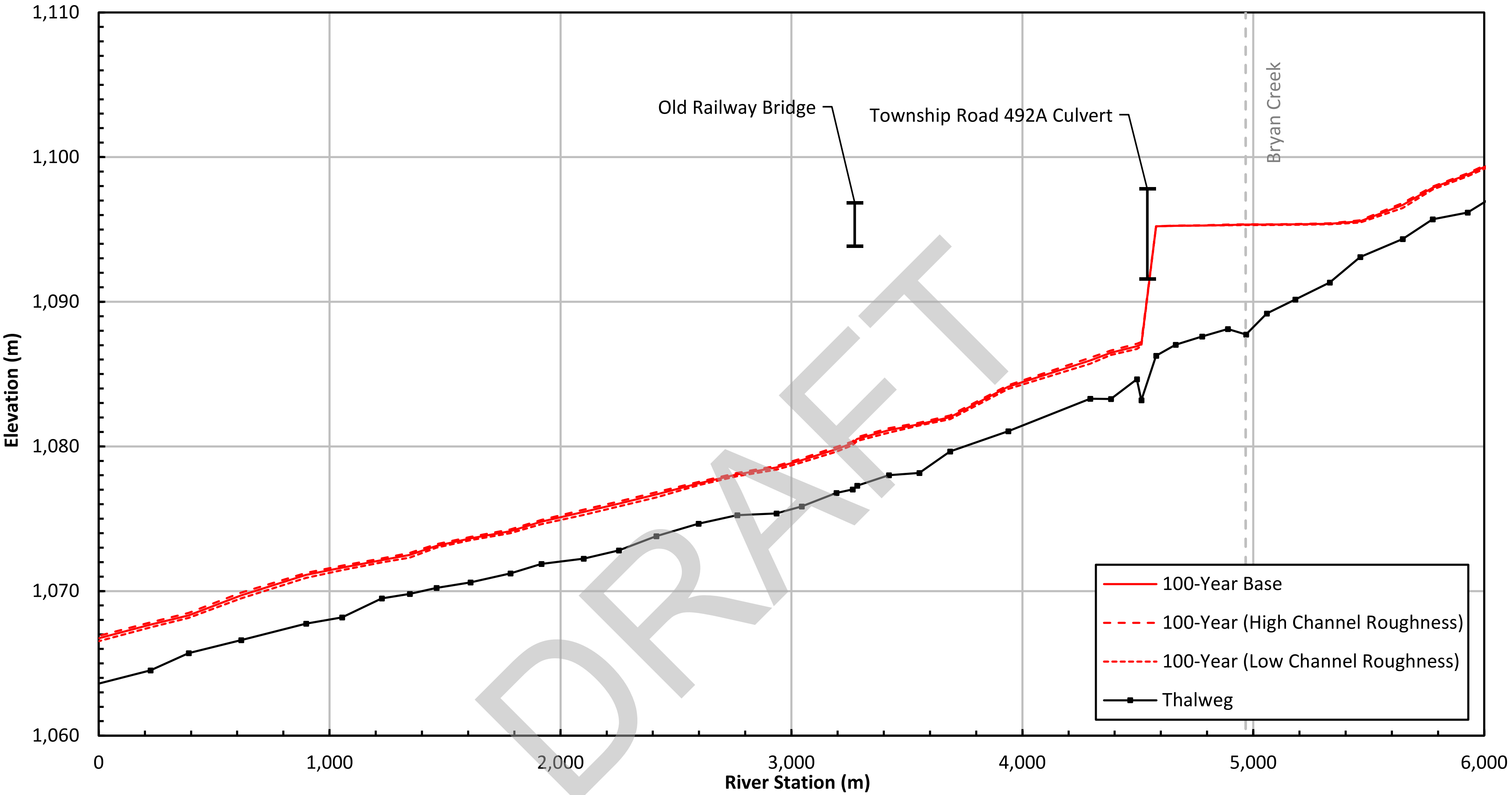
Date: 28-AUG-2025

ROBB FLOOD STUDY

EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – CHANNEL ROUGHNESS VALUE (1/2)

FIGURE 4.12



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Units: As Shown

Job: 1009252

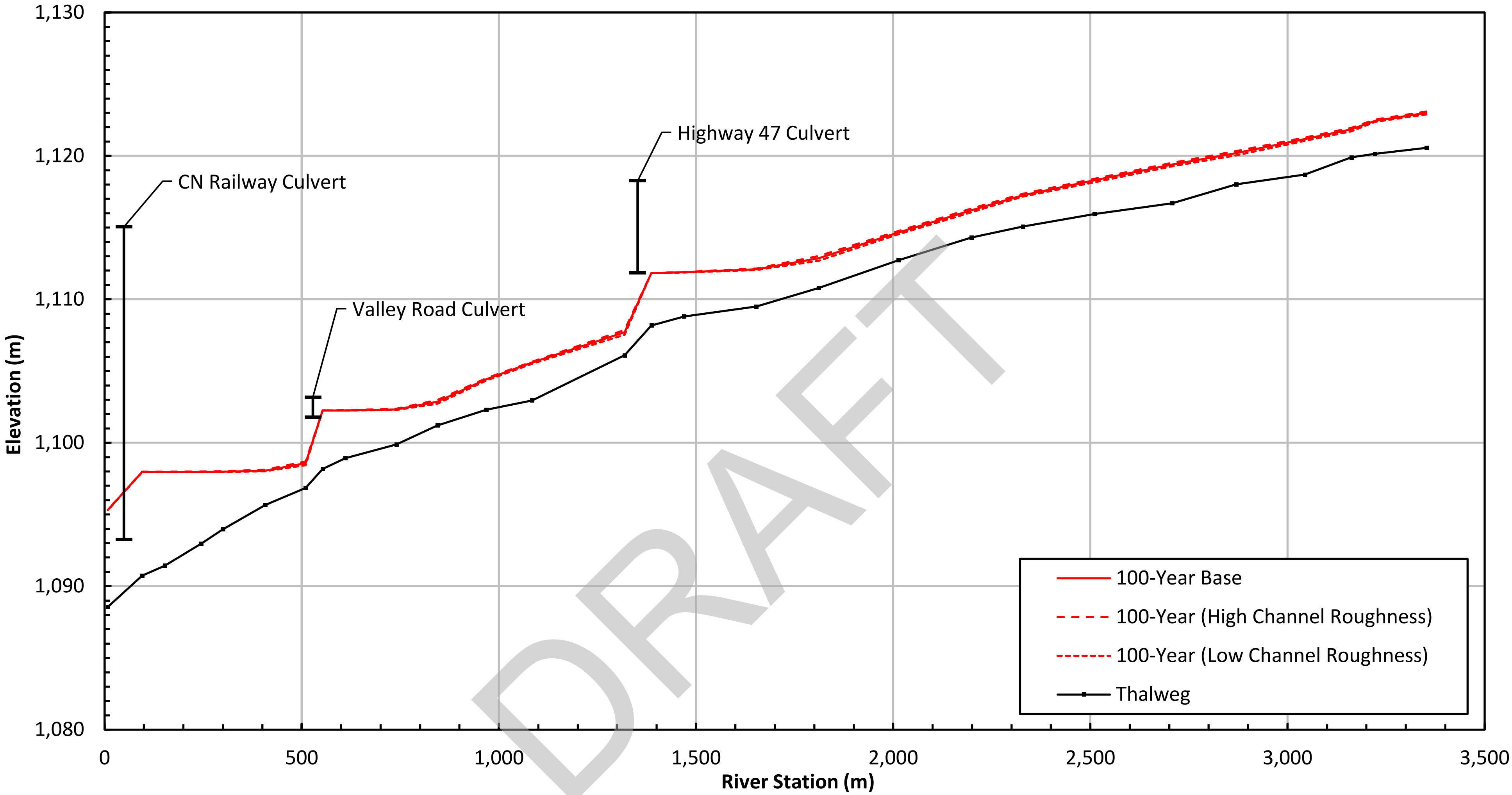
Date: 28-AUG-2025

ROBB FLOOD STUDY

EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – CHANNEL ROUGHNESS VALUE (2/2)

FIGURE 4.12

Classification: Public



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
nhc	Coordinate System: Units: As Shown	**BRYAN CREEK SENSITIVITY ANALYSIS PROFILE – CHANNEL ROUGHNESS VALUE**
	Job: 1009252 | *Date: 28-AUG-2025*	FIGURE 4.13

Classification: Public

The sensitivity of computed 100-year flood levels to overbank roughness variations was evaluated by selecting low and high roughness values for all land cover conditions in a single test. The range of varying overbank roughness coefficients were selected considering seasonal variations in vegetation growth and density. For the low and high roughness sensitivity runs, the overbank roughness values were adjusted by ± 20% from the base case to reflect this range (Table 4.10). The sensitivity analysis was run concurrently for Embarras River and Bryan Creek.

Table 4.10 Overbank roughness values used in sensitivity analysis

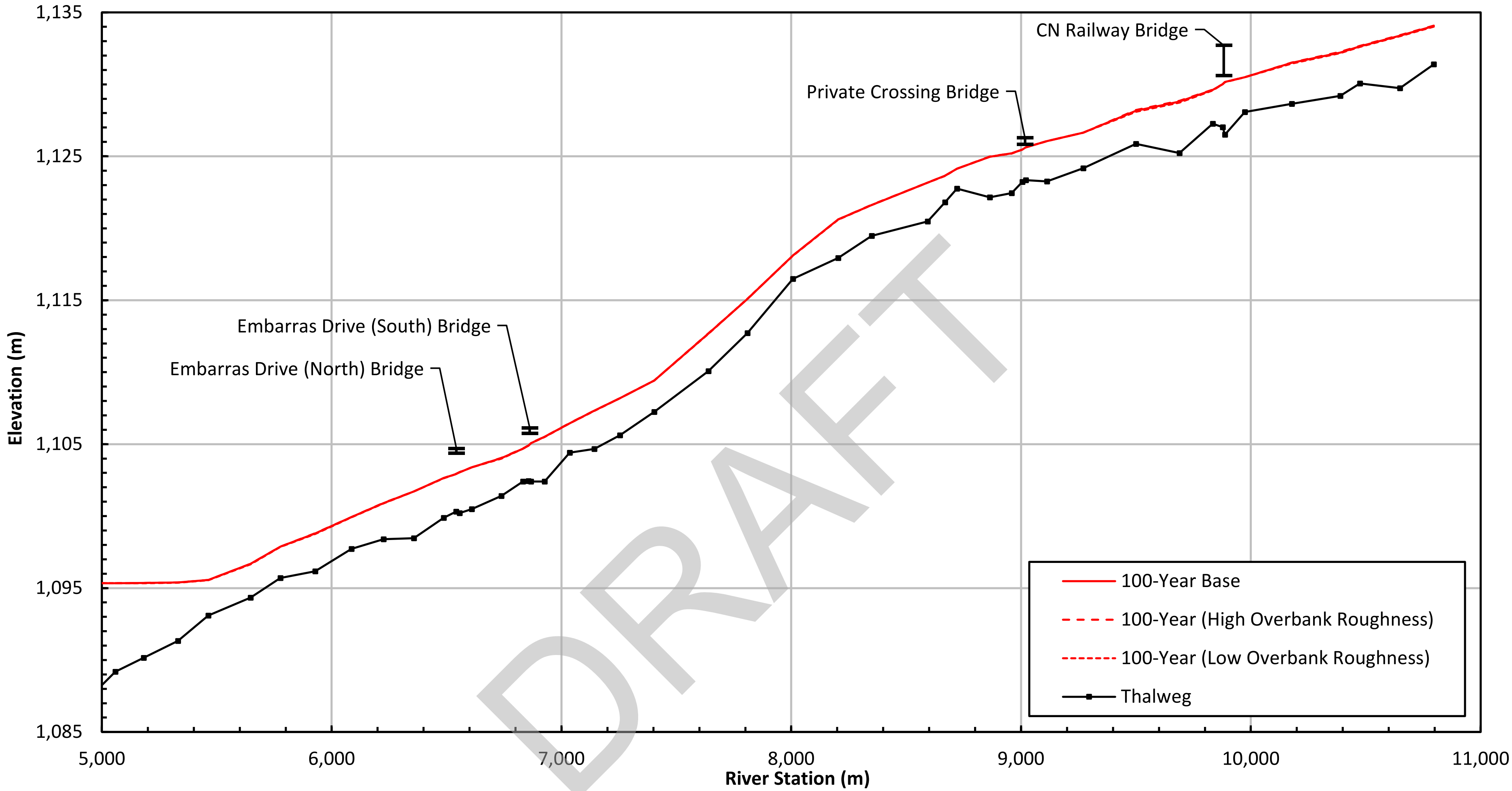
Land Cover	Overbank Roughness Value		
	Baseline	Low (-20%)	High (+20%)
Development within the wetted width of the design flood with buildings, yards, parks, and transportation corridors	0.085	0.068	0.102
Dense, willows, straight tree covered area	0.150	0.120	0.180

Figure 4.14 and Figure 4.15 show the variation in sensitivity test profiles from the baseline for the Embarras River and Bryan Creek. Table 4.11 presents the average and maximum changes in simulated water levels and inundation widths resulting from the range of tested overbank roughness values. Overall, variations in overbank roughness did not have significant effect on the simulated 100-year water levels and inundation extents across the study reaches. The maximum change in water level was 0.08 m, and the maximum change in inundation width was 9 m.

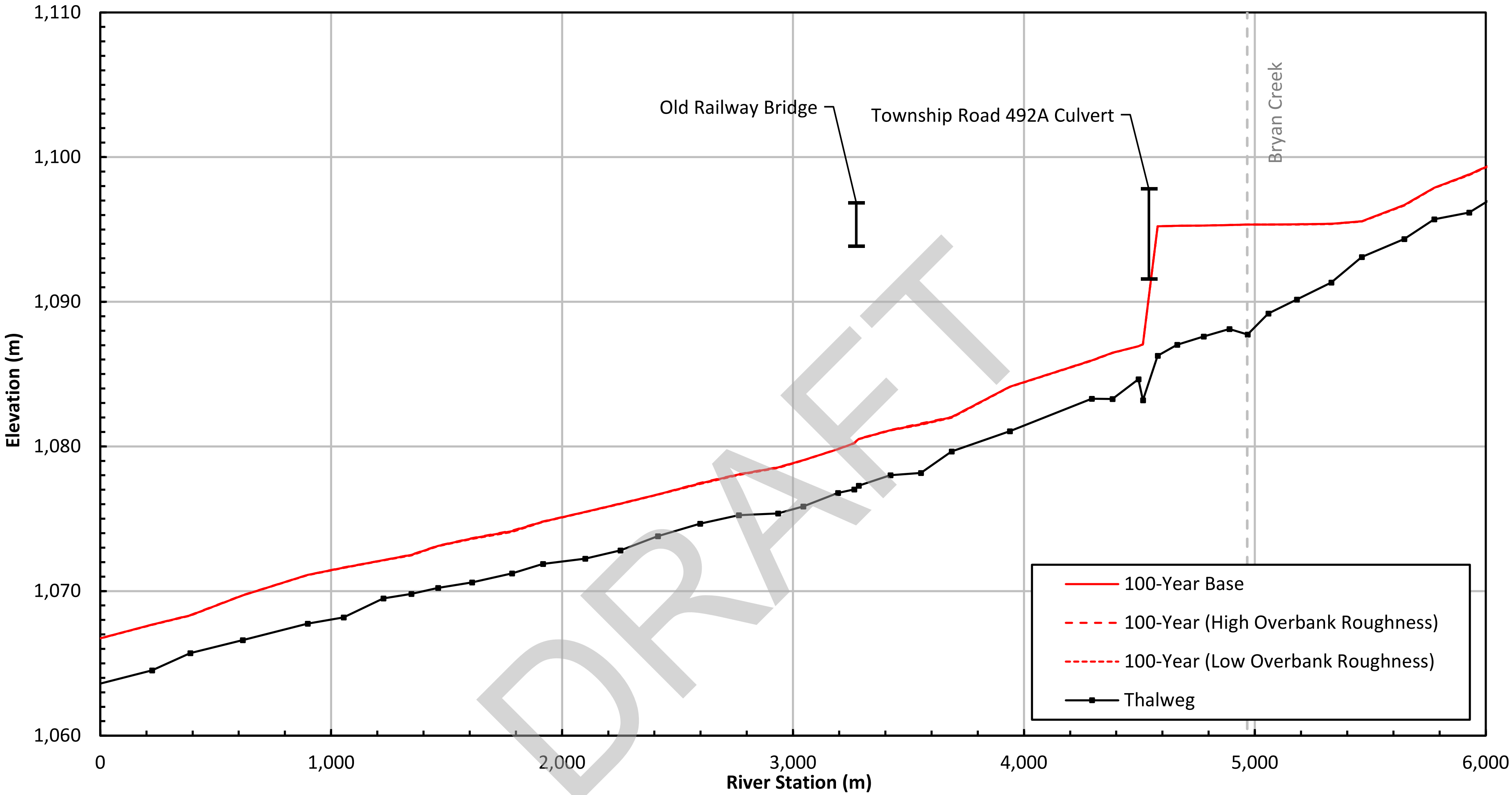
Table 4.11 Sensitivity analysis results to variation in overbank roughness

Parameter	Reach	Difference from Baseline Profile (m)			
		Low Roughness (-15%)		High Roughness (+15%)	
		Maximum	Average	Maximum	Average
Water Level/Flood Depth	Embarras River	-0.08	-0.02	0.05	0.01
	Bryan Creek	-0.04	-0.01	0.03	0.01
Inundation Width	Embarras River	-7	-1	9	1
	Bryan Creek	-1	0	1	0

Detailed results of overbank roughness sensitivity analysis are provided in **Appendix F.**



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY
nhc	Coordinate System: Units: As Shown	**EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – OVERBANK ROUGHNESS VALUE (1/2)**
	Job: 1009252 *Date: 28-AUG-2025*	FIGURE 4.14



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Units: As Shown

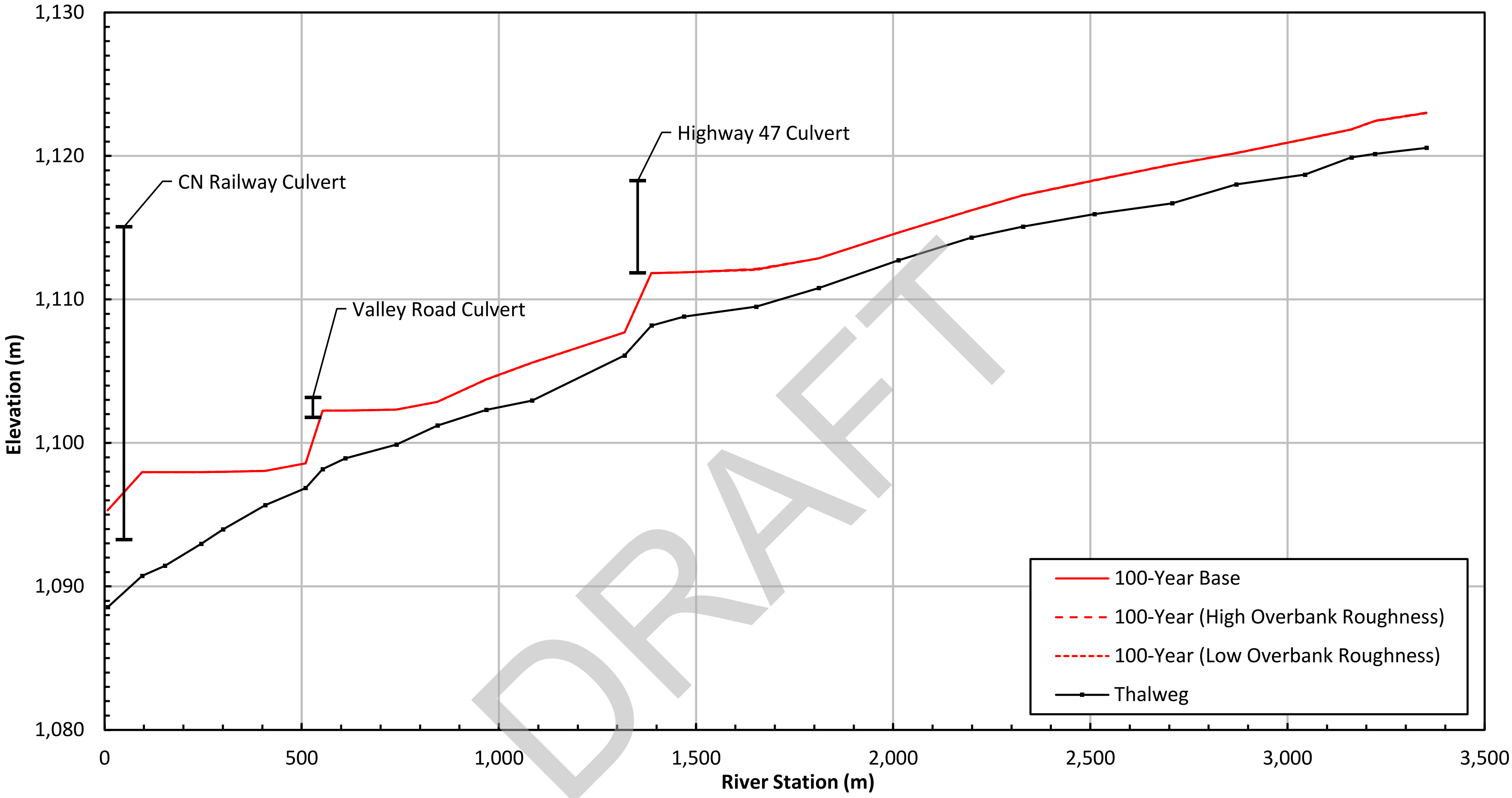
Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

EMBARRAS RIVER SENSITIVITY ANALYSIS PROFILE – OVERBANK ROUGHNESS VALUE (2/2)

FIGURE 4.14



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

BRYAN CREEK SENSITIVITY ANALYSIS PROFILE – OVERBANK ROUGHNESS VALUE

FIGURE 4.15

5 FLOOD INUNDATION MAPS

This section presents the methods and results of the flood inundation mapping, including the individual flood inundation map series created for each of the 13 flood frequency return periods from the 2-year through 1000-year scenarios. The open water inundation map series is provided in **Appendix G**. Flood inundation mapping shows areas of ground that could be covered by water under one or more flood scenarios for existing conditions**.**

5.1 Methodology

The methodology used to create the flood inundation maps is as follows.

- Create a WSE triangular irregular network (TIN) representing a contiguous flood level profile along the modelled river reaches.
- Generate a WSE grid with the same grid geometry as the underlying DTM. Assign elevation values to each grid cell based on the corresponding value taken from the WSE TIN.
- Generate a depth grid (with the same grid geometry as the WSE grid) by subtracting DTM elevations from the corresponding WSE grid values. Negative depth values represent dry cells and were assigned a value of *NoData*.
- Generate inundation polygons based on the depth grids by converting depths greater than 0 m into inundation polygons.
- Minimum flood/inundation extents were delineated for some small reach segments and for lower return periods, where the DTM (derived from LiDAR data) showed higher elevations than simulated water levels, likely due to debris blockage and/or deep pools caused by channel blockage and beaver dams. To prevent gaps, these extents were manually drawn using topographic features from the DTM, hillshade and aerial imagery, ensuring a smooth transition with adjacent inundation areas. The delineation process was guided by elevation changes in the DTM, variations in bank slope seen in the hillshade, and vegetation or wet areas identified in aerial imagery.
- The inundation polygons were further processed by smoothing, filtering out wetted areas that were not directly inundated (or "isolated"), and removing very small dry areas (or "holes"). A PAEK smoothing algorithm was applied with a 10 m threshold, which was determined to be appropriate for this project area. Additionally, a 100 m^2 filtering threshold was used to eliminate islands and holes smaller than this size.
- The bigger isolated areas were reviewed manually and removed if there are no hydraulic connections or separated by railway embankment. Some wetted areas not directly connected by overland flow were mapped as inundated if there was evidence of subsurface hydraulic connectivity through structures such as culverts or storm sewers or

separated by railway embankment. This assessment was based on a review of field-collected culvert and ditch data, aerial imagery, DTM, and other available information.

- The final inundation polygons were then used to clip the WSE grids and depth grids to the full inundation extent. The WSE TINs, WSE grids, depth grids, and inundation extent polygons were produced in standard Esri file formats using ArcGIS tool sets.

5.2 Water Surface Elevation TIN Modifications

Necessary modifications were made to the water surface elevation TIN for areas that needed manual edits (for example overbank flooding area or backwater area) so that inundation polygons could be re-generated from the data using the procedure described in Section 5.1 above.

Areas showing extensive overbank/backwater flooding directly connected to the channel at one distinct location (overtopping point) were adjusted such that the water surface elevation across that area was set equal to the water surface elevation at the overtopping point. This generally reduced the size of the inundated area upstream of an overtopping point and increased the size of the inundated area downstream of the overtopping point. When the size of the inundated area expanded downstream, NHC verified whether the extended area could potentially reconnect to the channel, ensuring a realistic representation in such instances.

Roadway crossings that were overtopped at a single distinct location (but were not fully submerged) were adjusted by setting the water surface elevation on top of the roadway crossing equal to the water surface elevation at the overtopped location. NHC applied the following steps for this adjustment.

- The weir flows reported by the HEC-RAS model were examined to determine if each road with a culvert crossing was overtopped (but not fully submerged) during a specific frequency flood event.
- If the road was found to overtop, a water surface elevation breakline was inserted at approximately the downstream shoulder of the road.
- The water level from the upstream model cross section was applied to the breakline.
- The updated breaklines were used to generate the water surface TINs.

No flood control structures were present within our study area. Thus, no manual modification to the TIN was required due to partial flood control structure failure.

The adjusted TIN surfaces were then used to generate the adjusted flood depth grids and flood inundation polygons so that each product incorporates the adjustments made.

5.3 Flood Inundation Area

The impacts of flooding on developed areas and infrastructure are evident in the flood inundation maps (**Appendix G**).

5.3.1 Direct Flood Inundation Areas

A list of notable areas that would potentially be impacted by floods is presented in Table 5.1. It provides a range of flood return periods (or frequencies) that could impact residential, commercial, recreational, and other notable facilities. The table lists areas from upstream to downstream, with reference cross section numbers to assist in cross-referencing with the inundation mapping libraries. The table also subdivided the impacted areas in between three communities (Upper Robb, Lower Robb, and Mile 34). The shaded boxes provide a graphical display of the approximate range of flood frequency magnitudes impacting each area.

No notable areas are anticipated to be flooded in Upper Robb. However, multiple houses in Lower Robb, near Embarras Drive, could be affected starting at the 20-year flood level. In the Mile 34 area, buildings and cabins may be impacted by 200-year or larger flood events. In Mile 34, one house located on the left bank of the Embarras River, just downstream of a private crossing bridge, is situated near a steep, eroded bank. Although this house would not be inundated for any of the modelled flood frequencies, bank erosion during floods is a potential hazard at this location. For detailed flood inundation maps, refer to **Appendix G**.

5.3.2 Hydraulic and Flood Control Structures

A total of nine crossings are located along the modelled reaches of the Embarras River and Bryan Creek: five bridges and four culverts. Of the five bridge crossings, only the private crossing bridge would be impacted at the 350-year flood.

Of the four culverts within the study area, the Township Road 492A and Valley Road culverts would likely be overtopped during the 350-year and larger floods. All culverts would be fully submerged during 200-year and larger floods, while the Township Road 492A culvert would start getting submerged from the 10-year flood event. As noted throughout this report, this culvert is undersized with limited capacity to convey larger floods.

The summary of hydraulic structures impacted by different frequency floods is presented in Table 5.2. It provides a range of flood return periods (or frequencies) that could impact the hydraulic structures. For detailed road crossing inundation mapping, please refer to **Appendix G**.

No flood control structures were identified within the study area.

Table 5.1 List of notable areas impacted by the range of flood magnitudes

River	Reach	Cross Section Reference	Impacted Areas along Floodplain for different Flood Frequency Events	2-YR	5-YR	10-YR	20-YR	35-YR	50-YR	75-YR	100-YR	200-YR	350-YR	500-YR	750-YR	1000-YR
Mile 34																
Embarras River	Above Bryan Creek	XS-72 to XS-70	Cabins located on the right bank and upstream of private crossing bridge													
		XS-72 to XS-71	Buildings located on the left bank and upstream of private crossing bridge													
Lower Robb																
Embarras River	Above Bryan Creek	XS-58 to XS-54	Outbuildings located on the left bank along Embarras Drive and upstream of south bridge													
		XS-58 to XS-54	Multiple houses located on the left bank along Embarras Drive and upstream of south bridge													
		XS-53 to XS-49	Multiple houses located on the right bank along Embarras Driver between north and south bridges													
		XS-49	A single house on the left bank along Balkan Drive just upstream of Embarras Drive (North) Bridge													

Table 5.2 Summary of hydraulic structures impacted by the range of flood magnitudes

River	Description	Structure Type	River Station (m)	TEC Bridge File	2 Year	5 Year	10 Year	20 Year	35 Year	50 Year	75 Year	100 Year	200 Year	350 Year	500 Year	750 Year	1000 Year
Embarras River	CN Railway	Bridge	9,882	BF496	-	-	-	-	-	-	-	-	-	-	-	-	-
Embarras River	Private Crossing	Bridge	9,017	N/A	-	-	-	-	-	-	-	-	-	Affected	Affected	Affected	Affected
Embarras River	Embarras Drive (South)	Bridge	6,862	BF 70587	-	-	-	-	-	-	-	-	-	-	-	-	-
Embarras River	Embarras Drive (North)	Bridge	6,543	BF 76138	-	-	-	-	-	-	-	-	-	-	-	-	-
Embarras River	Old Railway	Bridge	3,274	N/A	-	-	-	-	-	-	-	-	-	-	-	-	-
Embarras River	Township Road 492A	Culvert	4,541	N/A	-	-	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Overtopped	Overtopped	Overtopped	Overtopped
Bryan Creek	Highway 47	Culvert	1,352	BF 70904	-	-	-	-	-	-	-	-	Submerged	Submerged	Submerged	Submerged	Submerged
Bryan Creek	Valley Road	Culvert	528	BF 73286	-	-	-	-	-	Submerged	Submerged	Submerged	Submerged	Overtopped	Overtopped	Overtopped	Overtopped
Bryan Creek	CN Railway	Culvert	49	N/A	-	-	-	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged

Notes:

- "Affected" – Flood water between bridge low and high chord (bridges).
- "Submerged" – Flood water above culvert obvert, but below road elevation (culverts).
- "Overtopped" – Flood water above the bridge high chord (bridges) or roadway crossing (culverts).
- "-" – Flood water below the bridge low chord (bridges) or culvert obvert (culverts).

6 FLOODWAY DETERMINATION

Flood hazard identification involves the delineation of floodway and flood fringe zones for a specified design flood. A description of key terms from the FHIP Flood Study Technical Guidelines (AEP, 2022), incorporating technical changes implemented in 2021 regarding how floodways are mapped in Alberta, is provided below.

6.1 Design Flood Selection

As defined in the guidelines, the design flood standard in Alberta is the 1:100 flood, which is a flood that has a 1% chance of occurring in any given year. The design flood can be based on either open water or ice jam flooding scenarios, depending on which scenario results in more severe flooding. The 1:100 flood has a statistical 100-year return period and is also referred to as the 100-year flood.

The 100-year open water flood was selected as the design flood for the study area. The discharge values for the 100-year open water flood are listed in Table 3.1**.**

6.2 Floodway and Flood Fringe Terminology

Flood Hazard Map

A flood hazard map is a specific type of flood map that identifies the area flooded or at risk of flooding for the 100-year design flood and divides that flood hazard area into floodway and flood fringe zones, and flood fringe sub-zones like the high hazard flood fringe and protected flood fringe. Flood hazard maps can also illustrate additional flood hazard information, including incremental areas at risk for more severe floods than the design flood, including the 200- and 500-year floods.

Floodway

When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard for the 100-year design flood, where flows are deepest, fastest, and most destructive. When a flood hazard map is updated, the floodway may no longer represent the area of highest hazard based on new information.

Flood Fringe

The flood fringe is the area outside of the floodway that is flooded or could be flooded during the 100-year design flood. The flood fringe typically represents areas with shallower, slower, and less destructive flooding, but it may also include high hazard flood fringe areas. Areas at risk of flooding behind flood berms may also be mapped as protected flood fringe areas.

High Hazard Flood Fringe

The high hazard flood fringe identifies areas within the flood fringe with deeper or faster moving water than the rest of the flood fringe. High hazard flood fringe areas are likely to be more significant in flood maps that are being updated, but they may also be included in new flood maps.

Protected Flood Fringe

The protected flood fringe identifies areas that could be flooded if dedicated flood berms fail or do not work as designed during the 100-year design flood, even if they are not overtopped. Protected flood fringe areas illustrate residual flood risk and do not differentiate between areas with deeper and faster moving water and shallower or slower moving water.

6.3 Flood Hazard Identification

6.3.1 Floodway Determination Criteria

In areas being mapped for the first time, the floodway typically represents the area of highest hazard where flows are deepest, fastest, and most destructive during the design flood. The following criteria, based on those described in current FHIP guidelines (AEP, 2022), were used to delineate the floodway in such cases:

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

When a flood hazard map is updated, an existing floodway will not change in most circumstances. Exceptions to this would be: (1) a floodway could get larger if a main channel shifts outside of a previously-defined floodway or (2) a floodway could get smaller if an area of previously-defined floodway is no longer flooded by the design flood. These criteria are not applicable to the Robb flood study, as this area is being mapped for the first time and no existing floodway delineation is available.

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

The floodway mostly followed along the 1 m depth contour and the main channel, with occasionally following the 1 m/s velocity criteria. The final floodway limits were determined in consultation with the EPA project team. The floodway limit stations and limiting criteria for each cross section are tabulated in **Appendix H**. The limits of the floodway (also denoted as the floodway boundary) intersect cross sections at the floodway limit stations. In some instances, the floodway limits were coincident with the inundation limits. This condition typically occurs when there is no viable flood fringe.

6.3.2 Design Flood Profile

The open water design flood levels presented in **Appendix H** were extracted from the HEC-RAS model for the 100-year flood. Figure 4.7 (for Embarras River) and

Figure 4.8 (for Bryan Creek) earlier in the document depict the 100-year flood profile, which is the design flood.

6.3.3 Floodway Criteria Maps

A floodway criteria map documents the technical information that helps define the floodway (AEP, 2022). The information on the maps includes:

- Inundation extents for the design flood.
- Areas where the depth of water is 1 m or greater and the corresponding 1 m depth contour.
- Areas where the computed velocity is 1 m/s or faster.
- The proposed floodway limits and, where applicable, the previous floodway boundary.
- Stranded areas of dry ground within the flood hazard area.
- The location and extent of all cross sections used in the HEC-RAS model.
- The extent of main channel at each cross section.

The floodway criteria maps for this study are provided in **Appendix I**.

The mapping exercise began with the computed water surface elevations and flow velocities for the open water design flood. The extent of inundation was then mapped using the general procedure described in Section 5. This procedure included generation of the corresponding water surface elevation (WSE) triangular irregular network (TIN), WSE grid, and flood depth grid.

Polygons representing 1 m or more than 1m deep areas, and 1 m depth contour lines were derived from the flood depth grid. The depth contours were then filtered and smoothed using the same parameters and procedures as those applied to determine the inundation extents.

Since a one-dimensional computational modelling approach was used for this study, flow velocities were only available at the cross section locations. HEC-RAS can apportion channel and overbank discharge into a maximum of 45 sub-sections at any cross section location. Discharge is apportioned based on the computed water level and a weighted flow area approach. This provides a convenient means to estimate the lateral variation in velocity across a section. For this study, the maximum number of velocity subsections were specified in the overbanks. The velocity values were assigned to the corresponding segments along each cross section. Those segments with velocities of 1 m/s or greater were emphasized on the maps to help visualize where local flow velocities were greater than or equal to 1 m/s.

6.3.4 Flood Hazard Maps

The flood hazard maps depict the floodway and flood fringe, including the high hazard flood fringe areas, for the design flood. The map also shows incremental areas at risk for more severe floods: the 200- and 500-year floods. The flood hazard maps are provided as **Appendix J**.

The limits of the floodway were delineated by the floodway boundary developed for the open water floodway criteria map. The floodway was represented as a contiguous polygon by including areas of high ground or areas of depth less than 1 m inside the floodway.

The design flood extent developed for the floodway criteria maps was adjusted to create the flood fringe. The limits of the flood fringe followed the extent of direct inundation of the design flood. Areas of high ground within the direct inundation extent (and outside of the floodway) were preserved and not indicated as flood fringe in the flood hazard map. High hazard flood fringe areas were differentiated in the flood hazard maps.

Areas in the Floodway

The floodway primarily includes the main channel and parts of the overbank areas, which are mostly forested, with no significant areas of interest.

Areas in the High Hazard Flood Fringe

The high hazard flood fringe includes all inundated areas outside the floodway with deeper or faster moving water. No notable areas are within the high hazard flood fringe.

Areas in the Flood Fringe

The flood fringe includes all inundated areas outside the limits of the floodway and high hazard flood fringe. Multiple houses located on the left and right bank of the Embarras River and along Embarras Drive are within the flood fringe.

7 POTENTIAL CLIMATE CHANGE IMPACTS

To address the potential impacts of climate change on flood levels, more severe open water flood scenarios were compared to the current design flood estimates to obtain a measure of "freeboard" that may be generally appropriate for long-term planning purposes. To obtain information appropriate for other applications, the simplified approach taken herein could be supplemented in the future by a more rigorous regional climate analysis and site-specific impact assessment.

7.1 Comparative Scenarios

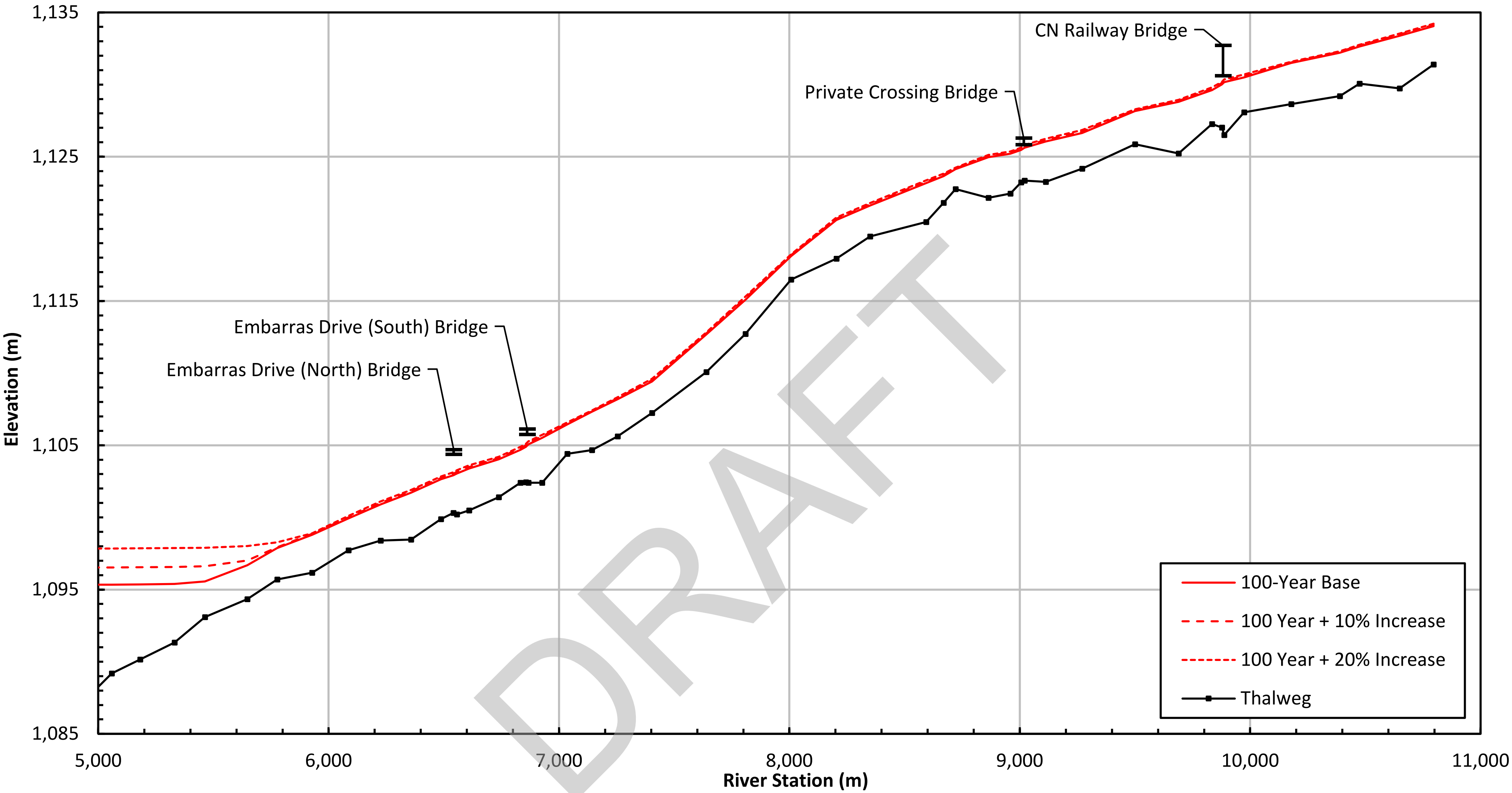
For the open water flood hazard, the current 100-year design flood water levels were compared to those associated with discharges that are 10 and 20% greater than the current 100-year flood estimates. This approach is consistent with guidelines prepared by Engineers and Geoscientists British Columbia (EGBC, 2018). EGBC recommends that for basins where no historical trend is detectable in local or regional streamflow magnitude frequency relations, a 10% increase in design discharge be applied to account for likely future changes in water input from precipitation. On the other hand, if a statistically significant trend is detected, a 20% increase may be appropriate, particularly for smaller basins.

7.2 Results

The results show that increases in discharge due to potential climate change can lead to substantial changes in water levels. A 10% increase in the 100-year flood discharge resulted in an average water level rise of up to 0.28 m, with a maximum of 1.76 m. A 20% increase led to an average rise of up to 0.61 m, with a maximum of 3.7 m. Figure 7.1 (for Embarras River) and Figure 7.2 (for Bryan Creek) compare the baseline 100-year flood profile with profiles generated using discharges increased by 10 and 20%. As shown in the figures, the most significant water level changes occurred in the backwater zone upstream of the Township Road 492A culvert, primarily due to its limited conveyance capacity. While increased discharge contributes to higher water levels, the impact is significantly amplified when flow is restricted by infrastructure capacity (for example the culvert here). Therefore, the large water level increases observed are more closely linked to the culvert's limited capacity than to the discharge increases alone due to potential climate change impacts.

7.3 Supplementary Information

Climate change has the potential to affect many factors related to flood severity. For open water floods, more frequent and greater intensity summer rain storms are commonly attributed to future climate flood risks. A comprehensive analysis would consider meteorological and hydrological factors at the basin scale to assess changes in flood peak discharges and their associated return periods.



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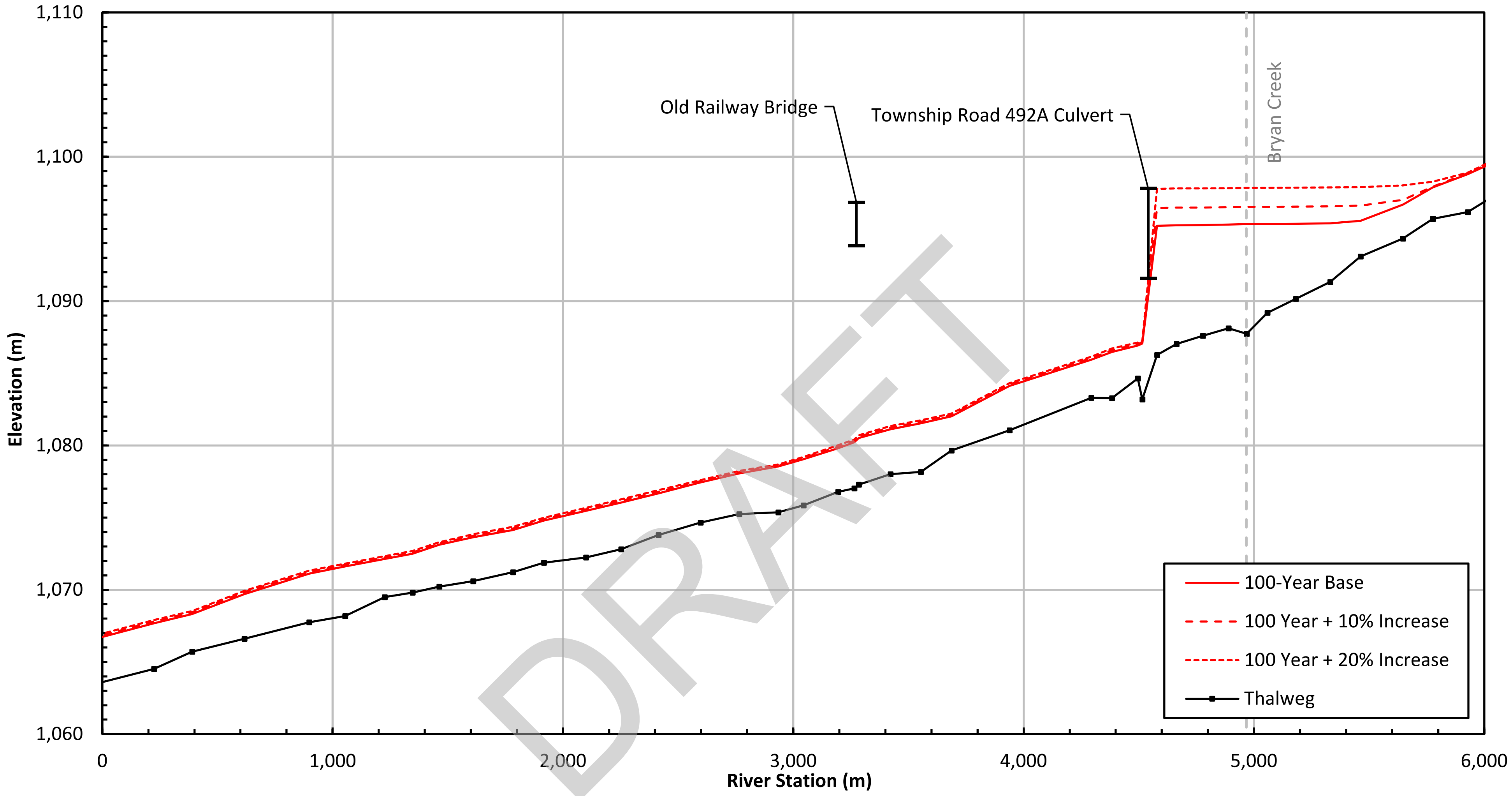
ROBB FLOOD STUDY

EMBARRAS RIVER POTENTIAL CLIMATE CHANGE IMPACTS ON DESIGN FLOOD PROFILE (1/2)

FIGURE 7.1



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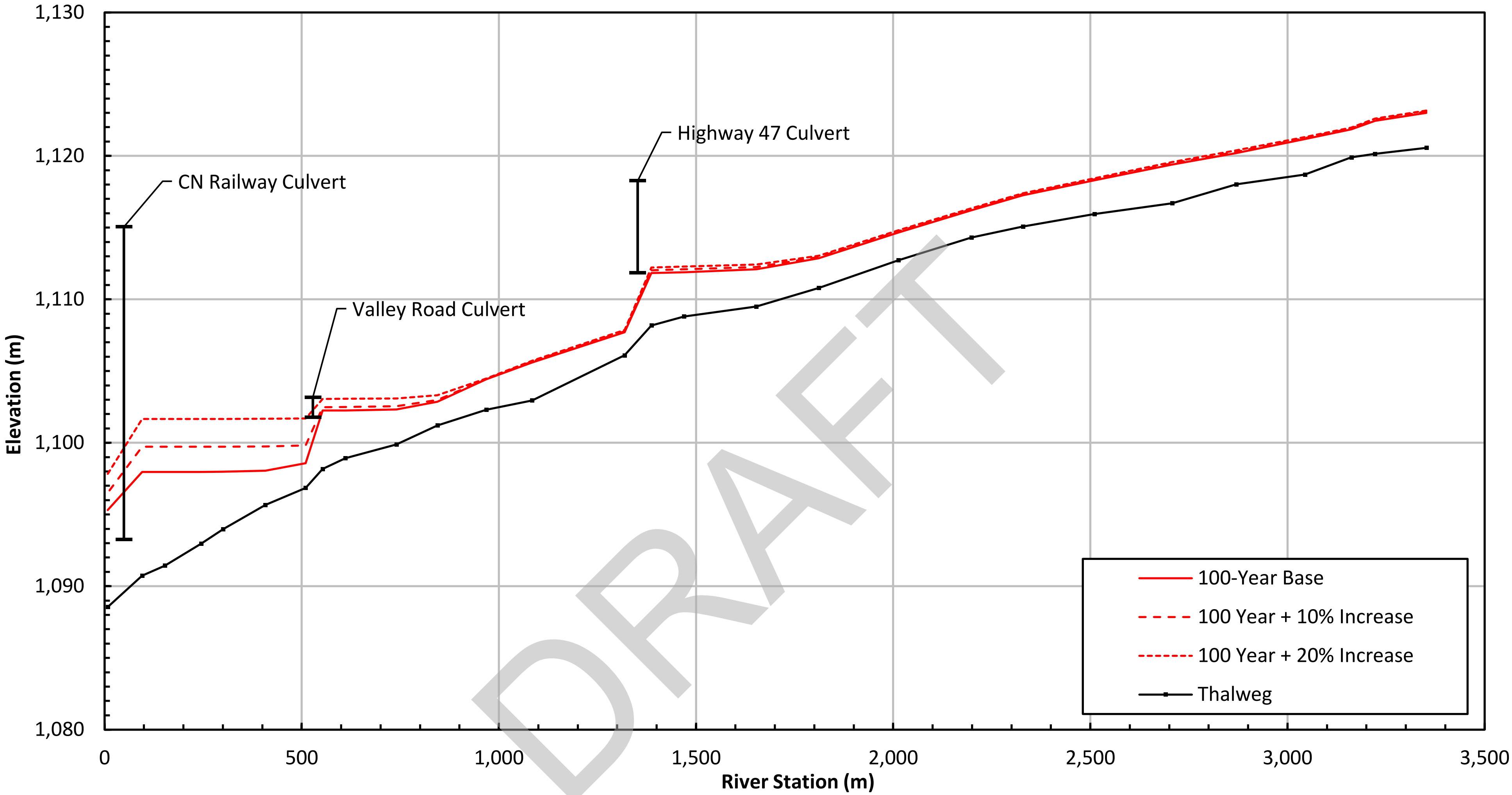
Date: 28-AUG-2025

ROBB FLOOD STUDY

EMBARRAS RIVER POTENTIAL CLIMATE CHANGE IMPACTS ON DESIGN FLOOD PROFILE (2/2)

FIGURE 7.1



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Coordinate System:
Units: As Shown

Job: 1009252

Date: 28-AUG-2025

ROBB FLOOD STUDY

BRYAN CREEK POTENTIAL CLIMATE CHANGE IMPACTS ON DESIGN FLOOD PROFILE

FIGURE 7.2

8 CONCLUSIONS

The objectives of this study were to assess riverine flood hazards along approximately 10 km of Embarras River and 3 km of Bryan Creek through Yellowhead County, including the Hamlet of Robb. No provincial flood mapping study was previously completed for the Hamlet of Robb, and the study reaches were mapped for the first time as part of this study.

The Robb Flood Study is comprised of five major project components: 1) survey and base data collection; 2) open water hydrology assessment; 3) open water hydraulic modelling; 4) open water flood inundation mapping; and 5) design flood hazard mapping. This report summarizes the work of all five components.

The collection of survey and base data primarily supports the hydraulic modelling and flood mapping. A total of 111 cross sections were surveyed along the study reaches using ground based surveys to complement the LiDAR-derived DTM of the overbank areas. In addition, geometric details were collected for five bridges and four culvert crossings along the study reaches. No dedicated flood control structures were identified during the site visit, survey, and discussion with EPA and the stakeholders. As part of the survey program, discharges and corresponding water levels were measured along the Embarras River and Bryan Creek study reaches. In addition to the survey data, DTM, aerial imagery, hydrometric data, HWM data, and other mapping features were gathered.

The primary purpose of the open water hydrology assessment was to develop flood frequency estimates for Embarras River and Bryan Creek, in support of the hydraulic modelling and flood mapping tasks. Three sites were identified for flood frequency estimates to capture the changes in creek discharge that would occur within the study area. The study reaches are not gauged, and the flood frequency flows were estimated based on the regional analysis. The current flood frequency estimates are in general lower than those from AENV (1984) and Associated (2001) studies, primarily due to differences in the selection of gauging stations for regional analysis. Additionally, this study incorporates longer flow records, selected homogenous regional basins, including more recent data, and utilizes advanced topographic datasets such as LiDAR DTM for basin delineation. As a result, the flood frequency estimates in this study have lower uncertainties compared to previous studies.

A hydraulic model of the study reach was developed using the HEC-RAS computer program. The model geometry was based on surveyed bathymetry and LiDAR DTM data. Upstream and downstream boundary conditions were specified, with inflow discharges assigned at the upstream boundaries of the Embarras River and Bryan Creek. A normal depth slope of 0.005 m/m was applied at the downstream boundary of the Embarras River, which was set 1 km downstream of the study area to minimize boundary effects on model results. Channel roughness values were selected through high flow calibration and verified using the literature and relevant regional studies. The June 2023 flood was selected as the calibration event, supported by available HWM data for the Embarras River. As the Embarras River is ungauged, NHC estimated the 2023 flood peak discharge and believed that it is associated with a 50-year return period. A calibrated channel roughness value of 0.064 was applied across all reaches, aligning well with literature values. Overbank roughness values were defined using land cover data, professional judgment, and literature guidance. Water surface profiles were generated for return periods of 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water flood scenarios. A sensitivity analysis was conducted on several model parameters, including upstream and downstream boundary conditions and Manning's roughness values for both channel and overbanks. The results indicated that the model is most sensitive to discharge and channel roughness, while sensitivity to other parameters was minimal. The unusually high sensitivity to discharge was attributed to the limited capacity of the Township Road 492A culvert and was observed only in the backwater area influenced by the culvert's constriction.

Flood inundation maps were created for various open water flood frequency return periods, ranging from 2- to 1000-year floods, using water surface profiles derived from hydraulic modelling. Multiple houses in Lower Robb along the Embarras Drive bridge are expected to be impacted by 20-year and larger floods, while buildings and cabins in Mile 34 area are expected to be impacted as early as from a 200-year flood. Of the nine hydraulic structures within the study reach, three culverts are projected to be submerged by the 100-year flood, and all bridges and culverts will be affected by the 1000-year flood. Among them two culvert crossings (Township Road 492A and Valley Road) are going to be overtopped by 350-year flood. No flood control structures were identified within the study area.

Floodway criteria maps were developed for the 100-year design flood, showing the criteria used to define the floodway and flood fringes. The floodway boundary largely follows the 1 m depth, and main channel, with occasionally following 1m/s velocity and inundation extent criteria (when no viable flood fringe). Flood hazard maps were later created to illustrate the floodway, flood fringe, and high hazard flood fringe areas for the design flood, along with incremental risk areas for the 200- and 500-year floods. No significant overbank areas are located within the floodway.

9 REFERENCES

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September 2025

APPENDIX A

SURVEY OVERVIEW MAP

Robb Flood Study
Main Report

SHEET 2 ↑

Alberta Canada

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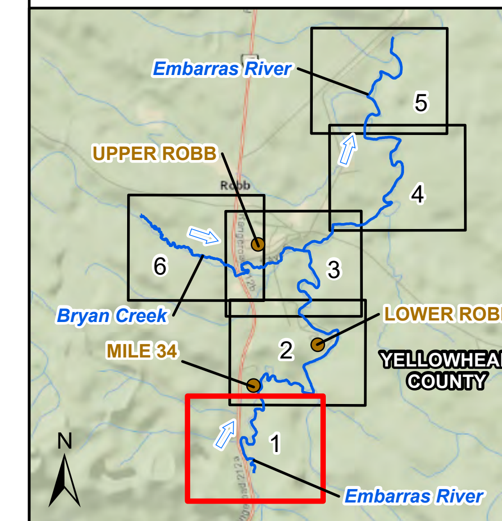


- CONTROL POINT
- SURVEY POINT
- RIVER STATION MARKER
- STUDY REACH
- SURVEY CROSS SECTION
- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- CULVERT
- RAILWAY
- STUDY LIMIT
- FLOW DIRECTION

SCALE - 1:5,000
0 50 100 M
N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

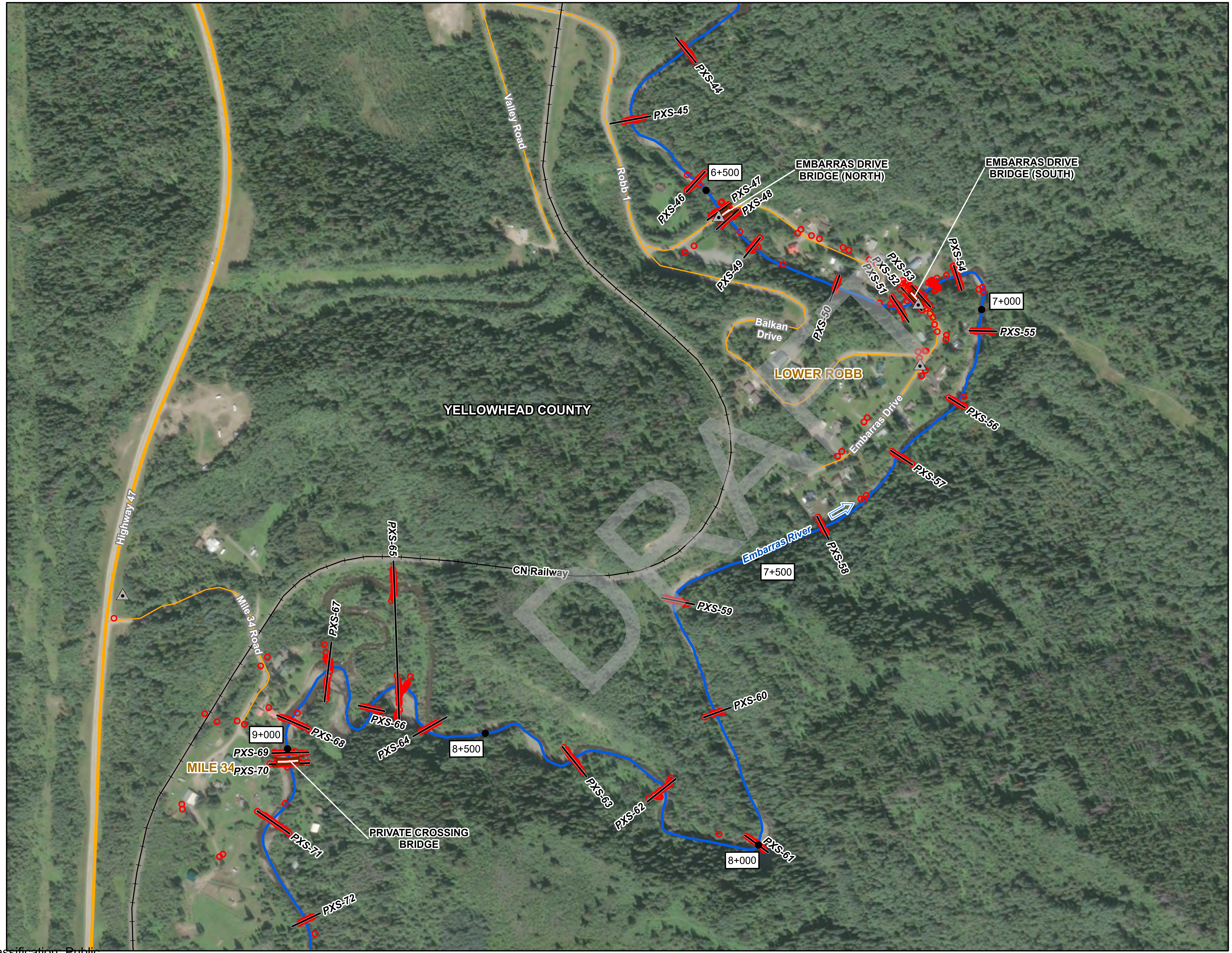
Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

SURVEY OVERVIEW

SHEET 3 ↑

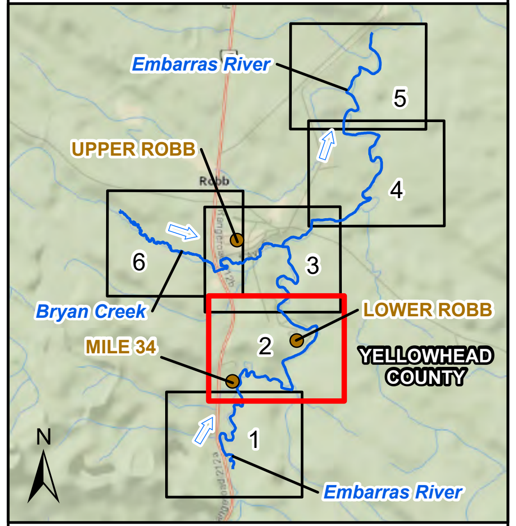


SHEET 1 ↓

Classification: Public

Alberta Canada

nhc



- CONTROL POINT
- SURVEY POINT
- RIVER STATION MARKER
- STUDY REACH
- SURVEY CROSS SECTION
- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- CULVERT
- RAILWAY
- STUDY LIMIT
- FLOW DIRECTION

SCALE - 1:5,000
0 50 100 M

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

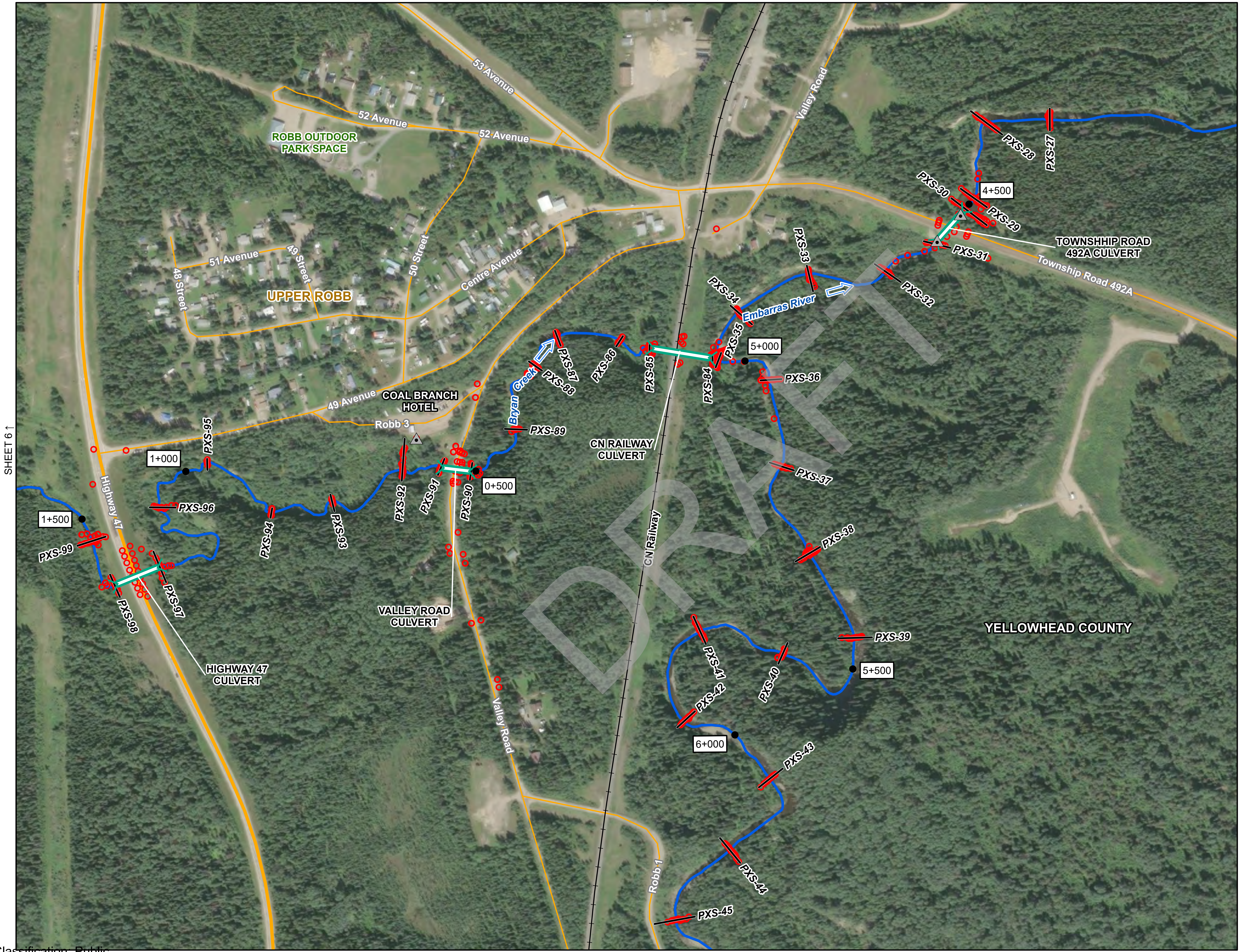
Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

SURVEY OVERVIEW

SHEET 4 ↑



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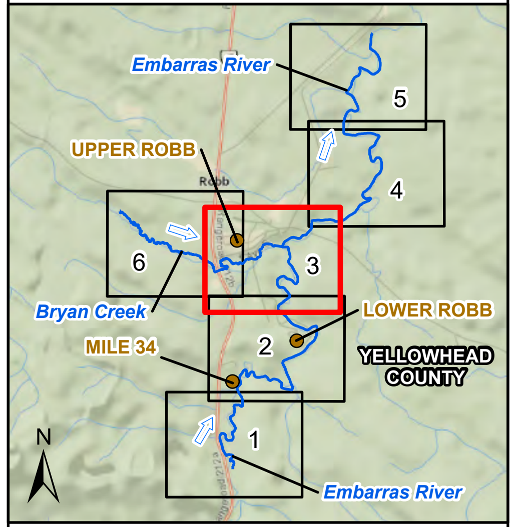
SHEET 2 ↓



▲	CONTROL POINT
○	SURVEY POINT
●	RIVER STATION MARKER
—	STUDY REACH
—	SURVEY CROSS SECTION
—	MAJOR HIGHWAY
—	LOCAL ROAD
	BRIDGE
	CULVERT
	RAILWAY
	STUDY LIMIT
⇨	FLOW DIRECTION

SCALE - 1:5,000

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Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

SURVEY OVERVIEW

SHEET 3 OF 6

JY: P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\SURVEY\ROBB FS SURVEY OVERVIEW.aprx

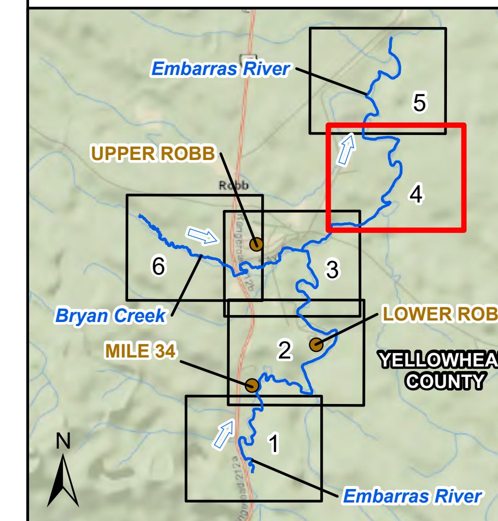
SHEET 5 ↑

SHEET 3 ↓

Classification: Public

Alberta Canada

nhc



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RIVER STATION MARKER
STUDY REACH
SURVEY CROSS SECTION
MAJOR HIGHWAY
LOCAL ROAD
BRIDGE
CULVERT
RAILWAY
STUDY LIMIT
FLOW DIRECTION

SCALE - 1:5,000
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Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

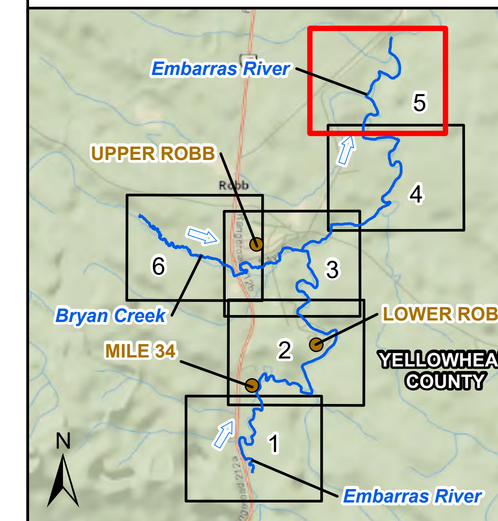
SURVEY OVERVIEW

Classification: Public

SHEET 4 ↓

Alberta Canada

nhc



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- FLOW DIRECTION

SCALE - 1:5,000
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Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

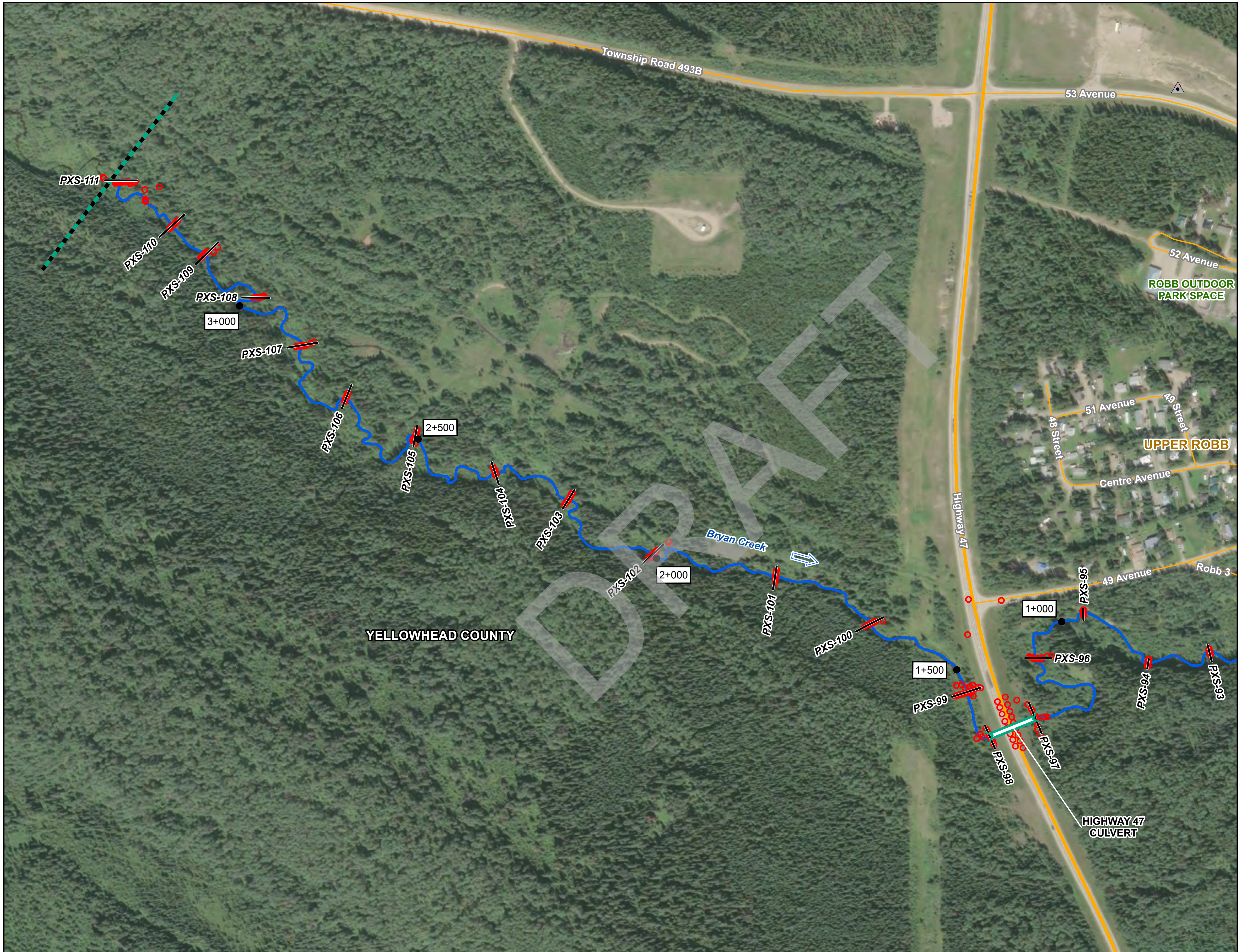
Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

SURVEY OVERVIEW

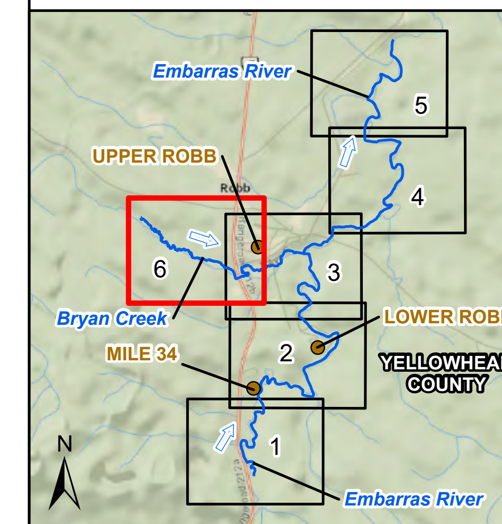
SHEET 5 OF 6

JY: P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\SURVEY\ROBB FS SURVEY OVERVIEW .aprx



Alberta Canada

nhc



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- SURVEY CROSS SECTION
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SCALE - 1:5,000
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Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	29-JUL-2025

ROBB FLOOD STUDY

SURVEY OVERVIEW

September 2025

APPENDIX B

HYDRAULIC STRUCTURE DETAILS

Robb Flood Study
Main Report

Bridge Description

Name:	CN Railway Bridge	**Bridge File No.:**	N/A
River:	Embarras River	**River Station (m):**	9,882

Geometry

Span (m):	21.9	**Minimum High Chord (m):**	1132.71
Width (m):	4.7	**Minimum Low Chord (m):**	1130.61
Pier Type:	N/A	**No. of Piers:**	0
Pier Shape:	N/A	**Pier Width (m):**	N/A

Photo(s)

Looking downstream at the upstream side of the bridge

Looking upstream at the downstream side of the bridge

Bridge Description

Name:	Private Crossing Bridge	**Bridge File No.:**	N/A
River:	Embarras River	**River Station (m):**	9,017

Geometry

Span (m):	31.7	**Minimum High Chord (m):**	1126.28
Width (m):	2.3	**Minimum Low Chord (m):**	1125.83
Pier Type:	Wood	**No. of Piers:**	1
Pier Shape:	Circular	**Pier Width (m):**	0.2

Photo(s)

Looking downstream at the upstream side of the bridge

Looking upstream at the downstream side of the bridge

Bridge Description

Name:	Embarras Drive Bridge South	**Bridge File No.:**	BF70587
River:	Embarras River	**River Station (m):**	6,862

Geometry

Span (m):	19.4	**Minimum High Chord (m):**	1106.12
Width (m):	6.4	**Minimum Low Chord (m):**	1105.73
Pier Type:	N/A	**No. of Piers:**	0
Pier Shape:	N/A	**Pier Width (m):**	N/A

Photo(s)

Looking downstream at the upstream side of the bridge

Looking upstream at the downstream side of bridge

Bridge Description

Name:	Embarras Drive Bridge North	**Bridge File No.:**	BF76138
River:	Embarras River	**River Station (m):**	6,543

Geometry

Span (m):	19.2	**Minimum High Chord (m):**	1104.69
Width (m):	6.1	**Minimum Low Chord (m):**	1104.36
Pier Type:	N/A	**No. of Piers:**	0
Pier Shape:	N/A	**Pier Width (m):**	N/A

Photo(s)

Looking downstream at the upstream side of the bridge

Looking upstream at the downstream side of the bridge

Bridge Description

Name:	Old Railway Bridge	**Bridge File No.:**	N/A
River:	Embarras River	**River Station (m):**	3,274

Geometry

Span (m):	114.9	**Minimum High Chord (m):**	1096.85
Width (m):	6.5	**Minimum Low Chord (m):**	1093.84
Pier Type:	Concrete	**No. of Piers:**	2
Pier Shape:	Rectangular	**Pier Width (m):**	2.0

Photo(s)

Looking downstream at the upstream side of the bridge

Looking upstream at the downstream side of the bridge

Culvert Description

Name:	Township Road 492A Culvert	**Bridge File No.:**	N/A
River:	Embarrass River	**River Station (m):**	4541

Geometry

Span (m):	N/A	**Upstream Invert Elev (m):**	1087.07
Diameter (m):	4.5	**Downstream Invert Elev (m):**	1085.86
Culvert Type:	CSP	**Barrel Length (m):**	54.9
Culvert Shape:	Circular	**Minimum Road Elevation (m):**	1097.79
Entrance Con:	Pipe projecting from fill		

Photo(s)

Looking downstream on upstream side of the culvert

Looking upstream on the downstream side of the culvert

Culvert Description

Name:	Highway 47 Culvert	**Bridge File No.:**	BF70904
River:	Bryan Creek	**River Station (m):**	1352

Geometry

Span (m):	N/A	**Upstream Invert Elev (m):**	1108.54
Diameter (m):	3.3	**Downstream Invert Elev (m):**	1106.78
Culvert Type:	CSP	**Barrel Length (m):**	64.1
Culvert Shape:	Circular	**Minimum Road Elevation (m):**	1118.26
Entrance Con:	Pipe projecting from fill		

Photo(s)

Looking downstream on the upstream side of the culvert

Looking upstream on the downstream side of the culvert

Culvert Description

Name:	Valley Road Culvert	**Bridge File No.:**	BF73286
River:	Bryan Creek	**River Station (m):**	528

Geometry

Span (m):	N/A	**Upstream Invert Elev (m):**	1098.77
Diameter (m):	3.0	**Downstream Invert Elev (m):**	1097.49
Culvert Type:	CSP	**Barrel Length (m):**	39.4
Culvert Shape:	Circular	**Minimum Road Elevation (m):**	1103.15
Entrance Con:	Pipe projecting from fill		

Photo(s)

Looking downstream on the upstream side of the culvert

Looking upstream on the downstream side of the culvert

Culvert Description

Name: CN Railway Culvert
River: Bryan Creek
Bridge File No.: N/A
River Station (m): 49

Geometry

Span (m): N/A
Diameter (m): 2.45
Culvert Type: Concrete
Culvert Shape: Rectangular
Entrance Con: Headwall Culvert
Upstream Invert Elev (m): 1090.80
Downstream Invert Elev (m): 1088.80
Barrel Length (m): 82.0
Minimum Road Elevation (m): 1115.05

Photo(s)

Looking downstream on upstream side of the culvert

Looking upstream on the downstream side of the culvert

September 2025

APPENDIX C

REACH REPRESENTATIVE PHOTOS

Robb Flood Study
Main Report

1) Looking upstream on Embarras River at upstream study boundary.

2) Looking downstream on Embarras River near PXS-80.

3) Looking downstream on Embarras River between PXS-72 & PXS-71.

4) Aerial view of Embarras River looking downstream at Mile 34 near PXS-71.

5) Looking downstream on Embarras River at PXS-64.

6) Aerial Shot of cutoff channel downstream of Mile 34 on Embarras River.

Note:

Photos taken by NHC during survey between 15 and 19 October 2024.

Alberta Canada

nhc

ROBB FLOOD STUDY

REACH REPRESENTATIVE PHOTOS – EMBARRAS RIVER

1009252	28-AUG-2025	**C-1**

In Mile 34, one house located on the left bank of the Embarras River, just downstream of a private crossing bridge, is situated near a steep, eroded bank (from 2023 flood). Although this house is not inundated under any of the modelled flood frequencies, the river bank is at

1) Looking downstream on Embarras River at PXS-59.

2)) Looking downstream near Lower Robb on Embarras River at PXS-55.

3) Aerial view of Lower Robb looking upstream on Embarras River near PXS-54.

4) Aerial view looking downstream on Embarras River at Embarras Drive Bridge near PXS-54.

5) Aerial view of Lower Robb looking upstream on Embarras River between PXS-50 and PXS 49.

6) Aerial view of looking upstream on Embarras River near PXS-45.

Note:

Photos taken by NHC during survey between 15 and 19 October 2024.

Alberta Canada

nhc

ROBB FLOOD STUDY

REACH REPRESENTATIVE PHOTOS – EMBARRAS RIVER

1009252	28-AUG-2025	**C-2**

In Mile 34, one house located on the left bank of the Embarras River, just downstream of a private crossing bridge, is situated near a steep, eroded bank (from 2023 flood). Although this house is not inundated under any of the modelled flood frequencies, the river bank is at

1) Looking downstream on Embarras River from PXS-43.

2) Looking at Confluence of Bryan Creek and Embarras River.

3) Looking upstream at Embarras River from CN Railway Culvert Embankment.

4) Looking upstream on Embarras River between PXS-33 & PXS-32.

5) Looking upstream on Embarras River near PXS-23.

6) Looking upstream on Embarras River near PXS-17.

Note:

Photos taken by NHC during survey between 15 and 19 October 2024.

Alberta Canada

nhc

ROBB FLOOD STUDY

REACH REPRESENTATIVE PHOTOS – EMBARRAS RIVER

1009252	28-AUG-2025	**C-3**

1) Looking downstream on Embarras River from PXS-10.

2) Aerial view looking upstream on Embarras River near PXS-07.

3) Looking upstream on Embarras River from PXS-04.

4) Aerial view of downstream survey reach on the Embarras River.

Note:

Photos taken by NHC during survey between 15 and 19 October 2024.

Alberta

Canada

nhc

ROBB FLOOD STUDY

REACH REPRESENTATIVE PHOTOS – EMBARRAS RIVER

1009252	28-AUG-2025	**C-4**

1) Looking upstream on Bryan creek from Highway 47 Culvert.

2) Aerial view looking upstream on Bryan Creek between PXS-96 & PXS - 97.

3) Looking upstream on Bryan Creek between PXS-92 and PXS-91.

4) Aerial view on Bryan Creek between PXS-87 & PXS-86.

5) From top of CN Embankment looking at Bryan Creek.

Note:

Photos taken by NHC during survey between 15 and 19 October 2024.

Alberta Canada

nhc

ROBB FLOOD STUDY

REACH REPRESENTATIVE PHOTOS – BRYAN CREEK

1009252	28-AUG-2025	**C-5**

September 2025

APPENDIX D

OPEN WATER HYDROLOGY ASSESSMENT

Robb Flood Study
Main Report

Northwest Hydraulic Consultants Ltd.
9819 – 12 Avenue SW
Edmonton, AB T6X 0E3
Tel: 780.436.5868
www.nhcwater.com

NHC Reference No. 1009252.01

June 24, 2025

Alberta Environment and Protected Areas
11th floor, Oxbridge Place
9820-106th Street NW
Edmonton, AB T5K 2J6

Attention: Hammad Javid
Via email: Hammad. Javid@gov.ab.ca

Re: Robb Flood Study
Open Water Hydrology Assessment

Dear Hammad:

This letter report presents the open water hydrology assessment conducted as part of the Robb Flood Study.

1 INTRODUCTION

In September 2024, Alberta Environment and Protected Areas (EPA) retained Northwest Hydraulic Consultants Ltd. (NHC) to complete a flood study for areas along approximately 10 km of the Embarras River and 3 km of Bryan Creek through Yellowhead County, including the Hamlet of Robb. This study is part of Alberta's Flood Hazard Identification Program (FHIP), which is intended to enhance public safety and reduce future flood damage in the province. Results from this study are also intended to inform local land use planning decisions, flood mitigation projects, and emergency response planning.

The scope of work for this study includes the following major components:

- survey and base data collection
- open water hydrology assessment
- open water hydraulic modelling
- open water flood inundation mapping
- design flood hazard mapping

- reporting and documentation

This letter report presents the results of the open water hydrology assessment, the primary objective of which is to develop flood frequency estimates for Embarras River, and its tributary Bryan Creek within the study area, in support of the hydraulic modelling and flood mapping tasks for the Robb Flood Study.

2 STUDY AREA

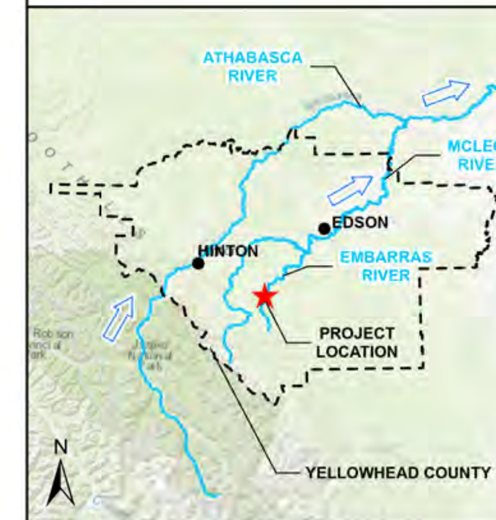
Figure 1 shows the location and boundaries of the study area, which includes:

- 10 km Embarras River extending from its south boundary at SE 10-49-21-W5M to its north boundary at NE 23-49-21-W5M,
- 3 km Bryan Creek extending from its west boundary at NE 16-49-21-W5M to its confluence with the Embarras River.

The study area includes the Hamlet of Robb and a portion of the Yellowhead County. The study area is located 50 km southwest of Edson, AB and 45 km southeast of Hinton, AB.

The terms of reference for this study do not specify the sites requiring flood frequency estimates. However, three key locations, identified in Figure 1, were chosen for this purpose in anticipation of significant changes in river discharge within the study area. The selected sites for flood frequency estimates are as follows:

- Embarras River above Bryan Creek
- Embarras River at downstream study boundary
- Bryan Creek at the mouth



FLOW DIRECTION
STUDY REACH
FLOOD FREQUENCY ESTIMATE SITES
WSC GAUGE STATION
ATS QUARTER SECTION

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:20,000
0 250 500 750 M
N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	PGV

Job Number	Date
1009252	18-NOV-2024

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD STUDY REACH AND FLOOD FREQUENCY ESTIMATE LOCATIONS

FIGURE 1

Classification: Public

3 HYDROLOGIC CHARACTERISTICS

This section of the report describes the hydrologic characteristics of the study area, including basin settings, sizes, and flood characteristics.

3.1 Basin Settings

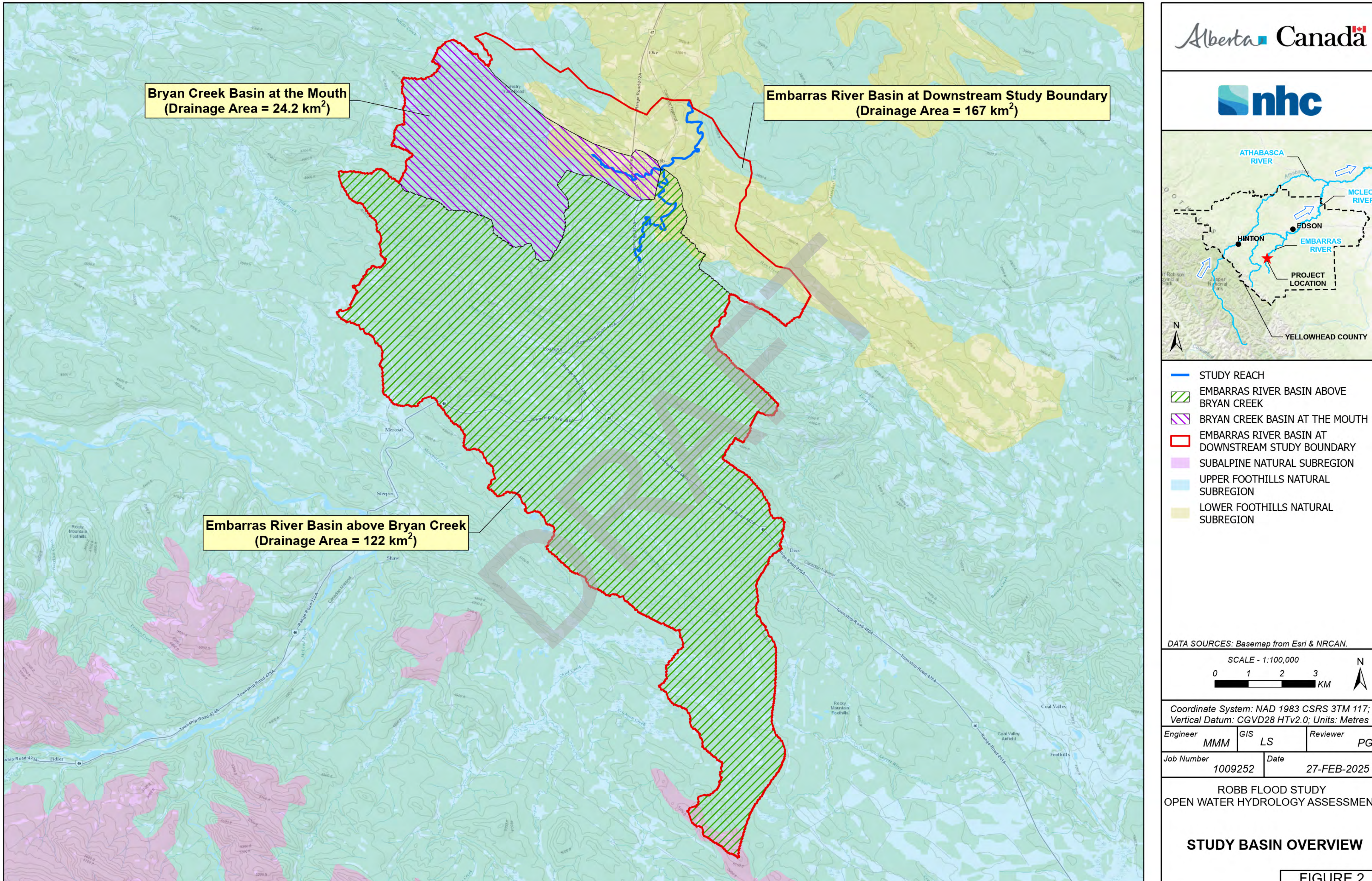
Embarras River is a major tributary of the McLeod River, which is a tributary of the Athabasca River. The river is a foothills stream, which originates in the mountain foothills east of Jasper National Park, and flows north through Robb, Alberta. From there, it flows northeast for approximately 80 km to its confluence with the McLeod River.

Bryan Creek is a tributary of the Embarras River. It flows in an easterly direction through the Hamlet of Robb before joining the Embarras River. Bryan Creek discharges to the Embarras River from a box culvert through a CN railway embankment.

Figure 2 illustrates the study basin areas overlaid on Alberta's natural subregions map (Natural Regions Committee, 2006). Alberta's land classification system divides the province into six natural regions and 21 subregions, defined by geographic patterns of vegetation, soil, and physiographic features that reflect the combined influence of climate, hydrology, topography, and geology. Most of the study basin areas lie within the Upper Foothills subregion. However, the lower portion of the Embarras River basin below Robb, along with part of the Bryan Creek basin, falls within the Lower Foothills subregion.

The Upper Foothills region is characterized by cooler year-round temperatures, shorter and wetter summers, and snowy winters. It receives significant precipitation, particularly in July. Proximity to the mountains contributes to its cooler summers and higher overall precipitation compared to lower-elevation areas.

In contrast, the Lower Foothills region experiences warmer summers and colder winters, with reduced precipitation, especially in winter. While July remains the peak month for precipitation, the annual average is slightly lower than that of the Upper Foothills. The Lower Foothills is more influenced by a continental climate, resulting in warmer and drier conditions overall.



Classification: Public

3.2 Basin Sizes

Figure 2 shows drainage areas upstream of the selected flood frequency estimate locations mentioned above. The sizes of these drainage areas are tabulated in Table 1. These drainage areas were determined based on the Water Survey of Canada (WSC) station information, National Hydrometric Network Basin Polygons (Government of Canada, 2024), and LiDAR 15 m digital elevation model (DEM) data.

Table 1: Summary of drainage areas for flood frequency estimate sites

Flood Frequency Estimate Location	Gross Drainage Area (km^2)
Embarras River above Bryan Creek	122
Embarras River at downstream study boundary	167
Bryan Creek at the mouth	24.2

3.3 Flood Characteristics

Long-term flow data are not available for the study reaches. The only WSC gauge station within the study area, WSC Station 07AF909 (Embarras River at Robb), was discontinued and provides only seasonal daily flow measurements from 1984 to 1988. Long-term flow monitoring data (1984-2024) for the Embarras River are available at WSC Station 07AF014 (Embarras River near Weald), located farther downstream with a larger drainage area of 640 km^2. Despite this difference in drainage area, data from WSC Station 07AF014 can be used to characterize flood patterns within the study area due to similar climatic and physiographic conditions.

Data from WSC Station 07AF014 indicate that most annual peak flows in the Embarras River occur between June and July, driven by snowmelt combined with major rainstorms in the foothills region. The largest flood on record occurred in June 2023, with a peak daily flow (estimated by WSC) of 179 m^3/s at WSC Station 07AF014 and an instantaneous peak flow of 211 m^3/s (estimated by NHC for this study). The second largest recorded flood was in early August 1987, with an instantaneous peak discharge of 145 m^3/s, followed by a similar peak of 143 m^3/s recorded in July 1999.

Systematic flow records for the Embarras River do not exist prior to 1984. However, historical flood levels at the Embarras Drive bridge (located in lower Robb), documented in Alberta Transportation and Economic Corridors (TEC) bridge file #76138, highlighted two major floods in July 1965 and August 1969. Another significant flood occurred in the region in 1980, with an estimated return period of approximately 35 years (AENV, 1984). Peak discharge estimates were not available for any of these floods.

Ice jams have not been a typical concern along the study reaches in the Robb Flood Study, so no breakup hydrology assessment was required.

4 REGIONAL STREAMFLOW DATA SERIES PREPARATION

A regional analysis was used to determine flood frequency estimates for Embarras River and Bryan Creek because these streams are not gauged within the study area.

For this study, six WSC gauge stations were selected for the regional analysis. These gauge stations are summarized in Table 2, and their locations and drainage basins are shown in Figure 3. These gauge stations were selected in consideration of various factors including their proximity to the study basin, basin size, length and period of record, basin landcover, topography, and climate condition.

Table 2: List of hydrometric stations selected for the regional analysis

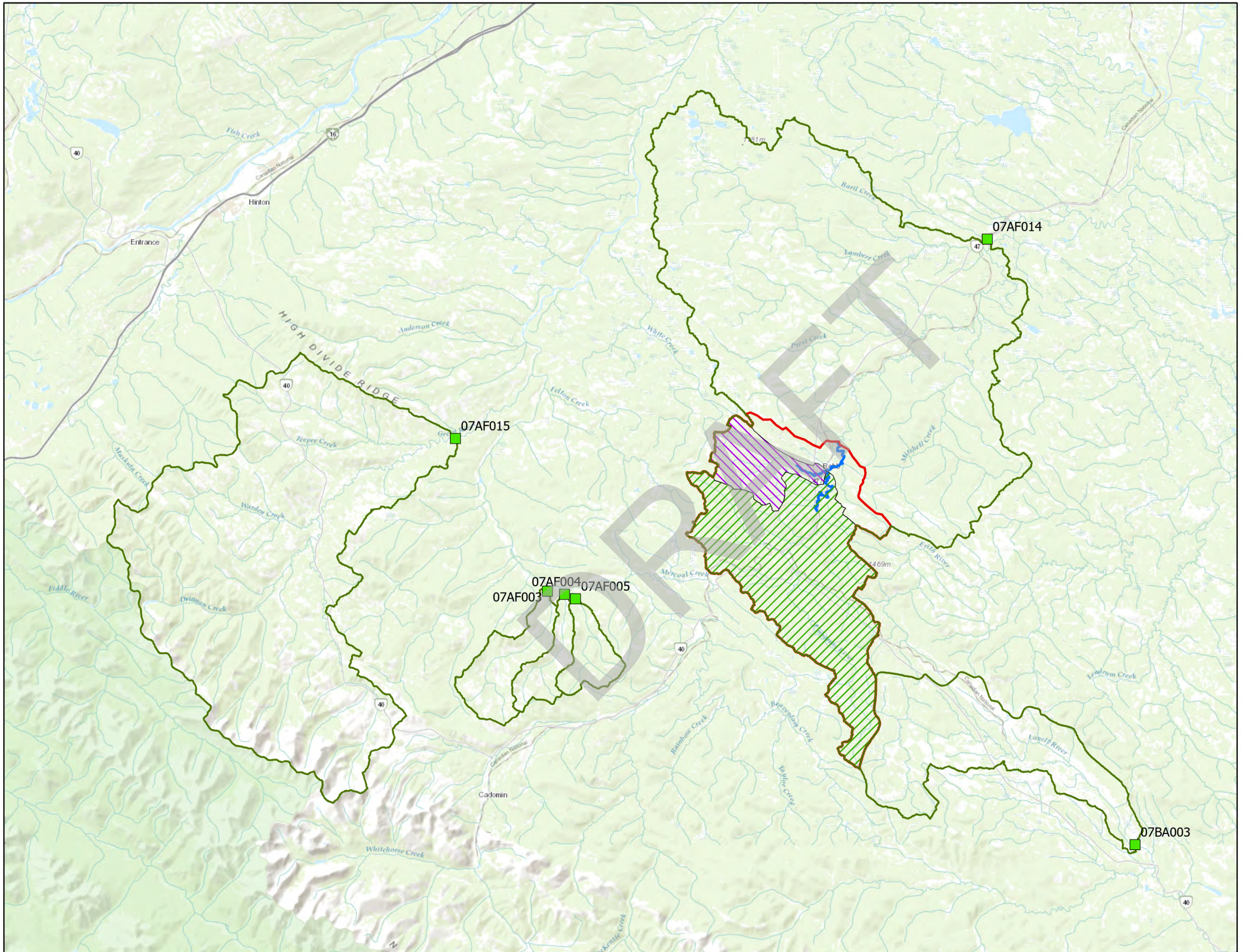
WSC Station ID	Station Name	Gross Drainage Area (km^2)[1]	Period of Record	Length of Record (years)	Distance of WSC Station from Study Site (km)
07AF004	Deerlick Creek near Hinton	14.9	1966-1990	25	20.0
07AF005	Eunice Creek near Hinton	16.1	1967-1992	26	19.5
07AF003	Wampus Creek near Hinton	27.2	1966-2023, 2024[2]	59	21.0
07BA003	Lovett River near the mouth	104	1975-2023, 2024[2]	50	33.5
07AF015	Gregg River near the mouth	381	1985-2022, 2023-2024[2]	40	26.0
07AF014	Embarras River near Weald	640	1984-2023, 2024[2]	41	19.5

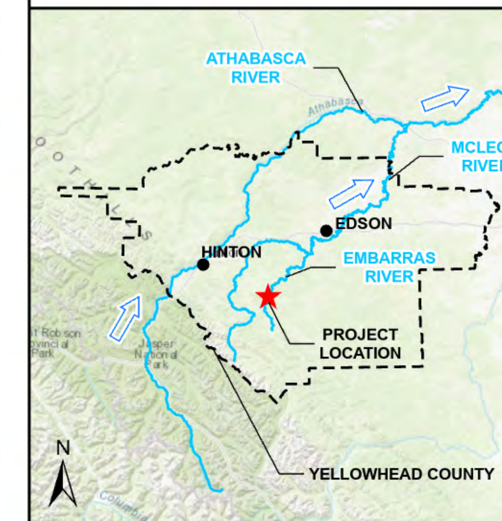
Notes:
1. The reported gross drainage area is based on National Hydrometric Network Basin Polygons (Government of Canada, 2024).
2. Preliminary data obtained from WSC.

Flow data including daily discharges, annual maximum daily discharges, and annual peak instantaneous discharges were collected from WSC for each of the selected regional stations. All data published by WSC have gone through their standard quality assurance and quality control process, and using these published data for flood frequency analysis is standard practice. NHC also collected unpublished preliminary data from WSC for 2023 and 2024 (as required). A review of the preliminary data showed that they appeared to be reasonable and suitable for inclusion in the flood frequency analysis.

Appendix A provides all data series used in the regional analysis, including annual peak instantaneous discharges (Q_i) and maximum daily discharges (Q_d) for each selected regional station. Flood peak data series were individually prepared for each station. For a given station, all available annual peak instantaneous values were used in the analysis. However, instantaneous peaks were not reported in many years. To address these gaps, NHC estimated the missing instantaneous peaks using daily discharge data from the corresponding years. For a given station, these estimates were based on the relationship between the instantaneous peak discharge (Q_i) and daily discharge (Q_d) observed in years where both were reported. This relationship, described in Equation 1, calculates the instantaneous peak to daily discharge ratio (R) for each station as the best fit between Q_i and Q_d, associated with the same flood event.

$$Q_i = R \times Q_d \qquad \textbf{(Equation 1)}$$





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- WSC STATION SELECTED FOR REGIONAL ANALYSIS
- STUDY REACH
- EMBARRAS RIVER BASIN ABOVE BRYAN CREEK
- BRYAN CREEK BASIN AT THE MOUTH
- EMBARRAS RIVER AT DOWNSTREAM STUDY BOUNDARY
- ROBB SELECTED BASIN FOR REGIONAL ANALYSIS

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:250,000

0 5 10 KM N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	PGV

Job Number	Date
1009252	27-FEB-2025

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

REGIONAL ANALYSIS BASIN OVERVIEW

FIGURE 3

Classification: Public

5 REGIONAL FLOOD FREQUENCY ANALYSIS

Regional analysis was performed to provide instantaneous peak discharge estimates for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1000-year open water floods, at the three flood frequency estimate locations in the study reaches.

The annual peak instantaneous discharges (Q_i) for each of the selected regional stations listed in Table 2 were normalized by their mean value (Q_{im}) and are plotted in Figure 4 against their empirical return periods (or plotting positions) based on the Cunnane formula (Cunnane, 1978). Different theoretical probability distributions including normal, log-normal (LN), three-parameter log-normal (3LN), Pearson type III (P3), log-Pearson type III (LP3), Gumbel, generalized extreme value (GEV), and Weibull were tested for each individual station. Appendix B contains plots of these tested flood frequency distributions for each of the selected regional stations. The P3 distribution is among the best in representing the historical flood data of the stations. The selected P3 distribution and confidence limits for each selected regional station are provided in Appendix C. As such, a normalized P3 curve was used to fit the normalized regional flow data. The normalized P3 curve shown in Figure 4 was computed by varying the standard deviation and coefficient of skewness within the respective ranges of the values for the selected gauge stations, until the total Sum of Standard Error (SSE) values (Equation 2) for the regional stations reached the minimum (1.05). In the equation below, n is number of data points, m is number of estimated parameters in the statistical model, x_i is the actual/observed value, y_i is the predicted value, and i is the index of data point.

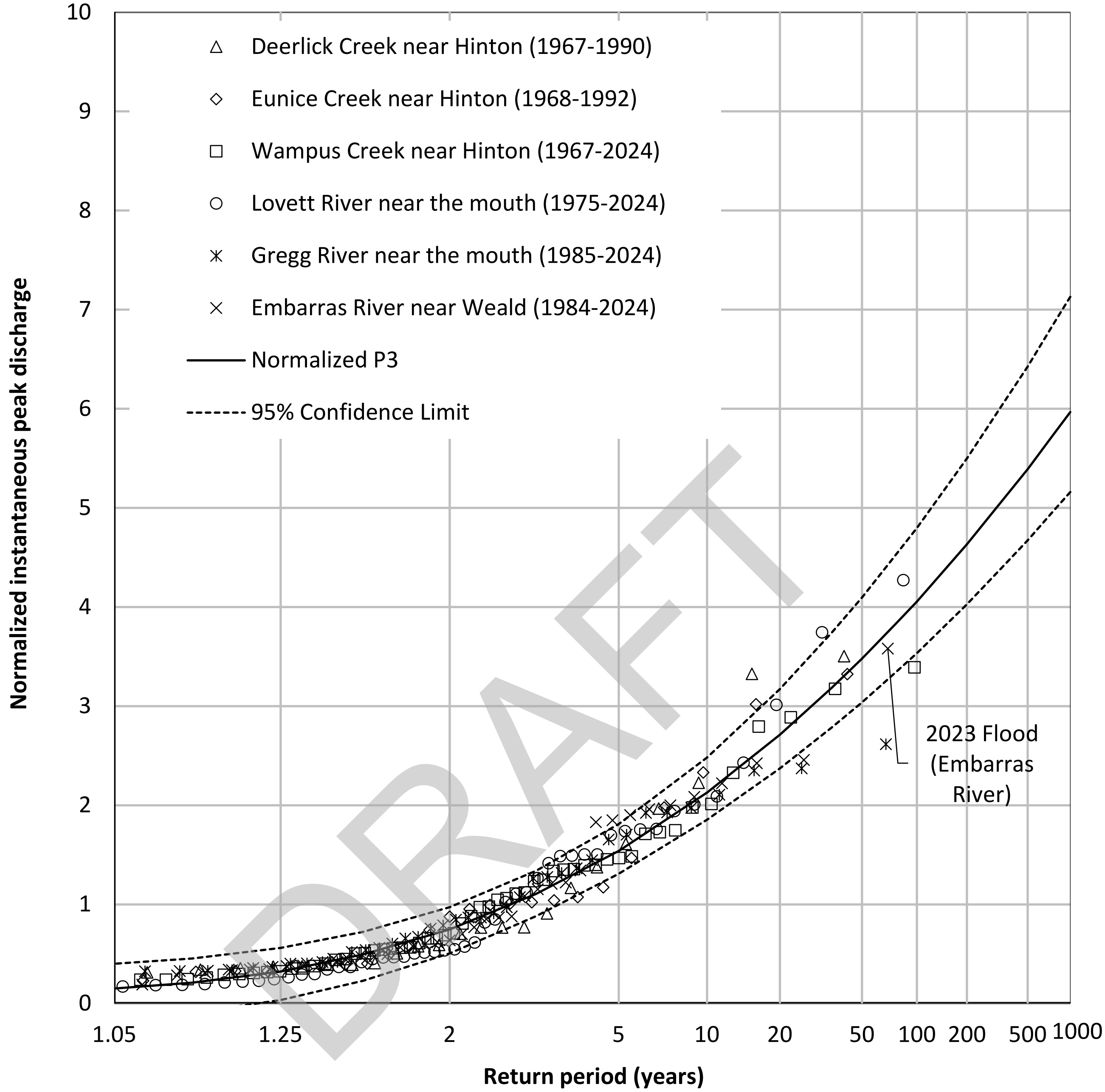
$$SSE = \sqrt{\frac{1}{n-m}\sum_{i=1}^{n}(x_i - y_i)^2} \qquad \textbf{(Equation 2)}$$

As shown in Figure 4, the curve fits all regional data points reasonably well. In addition, the normalized P3 curve fits the 2023 normalized flood peak for Embarras River near Weald, which further supports the reliability of our flood peak estimation. Figure 4 also shows the 95% confidence limits for the normalized P3 curve, which were estimated based on the average length of the regional flood data series (40 years).

Figure 5 shows the relationship between the mean annual peak discharges (Q_{im}) and drainage areas for the selected regional stations. It shows that the peak discharge is proportional to drainage area to the power of 0.80. Table 3 shows the mean annual peak discharges for the flood frequency estimate sites computed with the relationship shown in Figure 5.

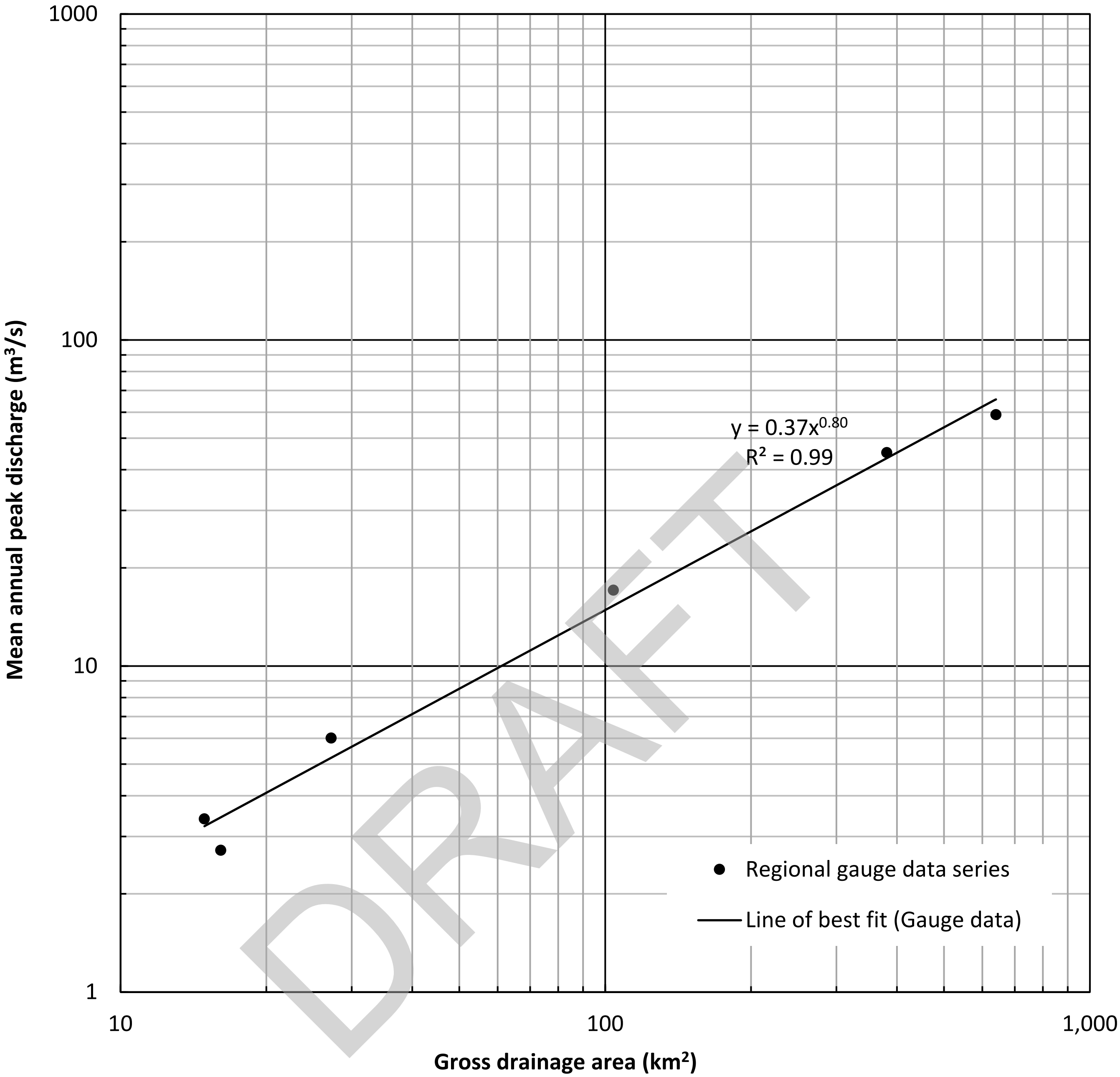
Table 3: Computed mean annual peak discharges for flood frequency estimate sites

Flood Frequency Estimate Location	Gross Drainage Area (km^2)	Mean Annual Flood Peak (m^3/s)
Embarras River above Bryan Creek	122	17.3
Embarras River at downstream study boundary	167	22.2
Bryan Creek at the mouth	24.2	4.73



Notes: 1. The Cunnane plotting position is used to plot the data.

Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
nhc	Coordinate System: Units: As Shown	**ADOPTED NORMALIZED P3 FLOOD FREQUENCY CURVE**
	Job: 1009252 / Date: 27-FEB-2025	FIGURE 4



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ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

RELATIONSHIP BETWEEN MEAN ANNUAL PEAK DISCHARGE AND DRAINAGE AREA

Coordinate System:
Units: As Shown

Job: 1009252 | *Date: 27-FEB-2025*

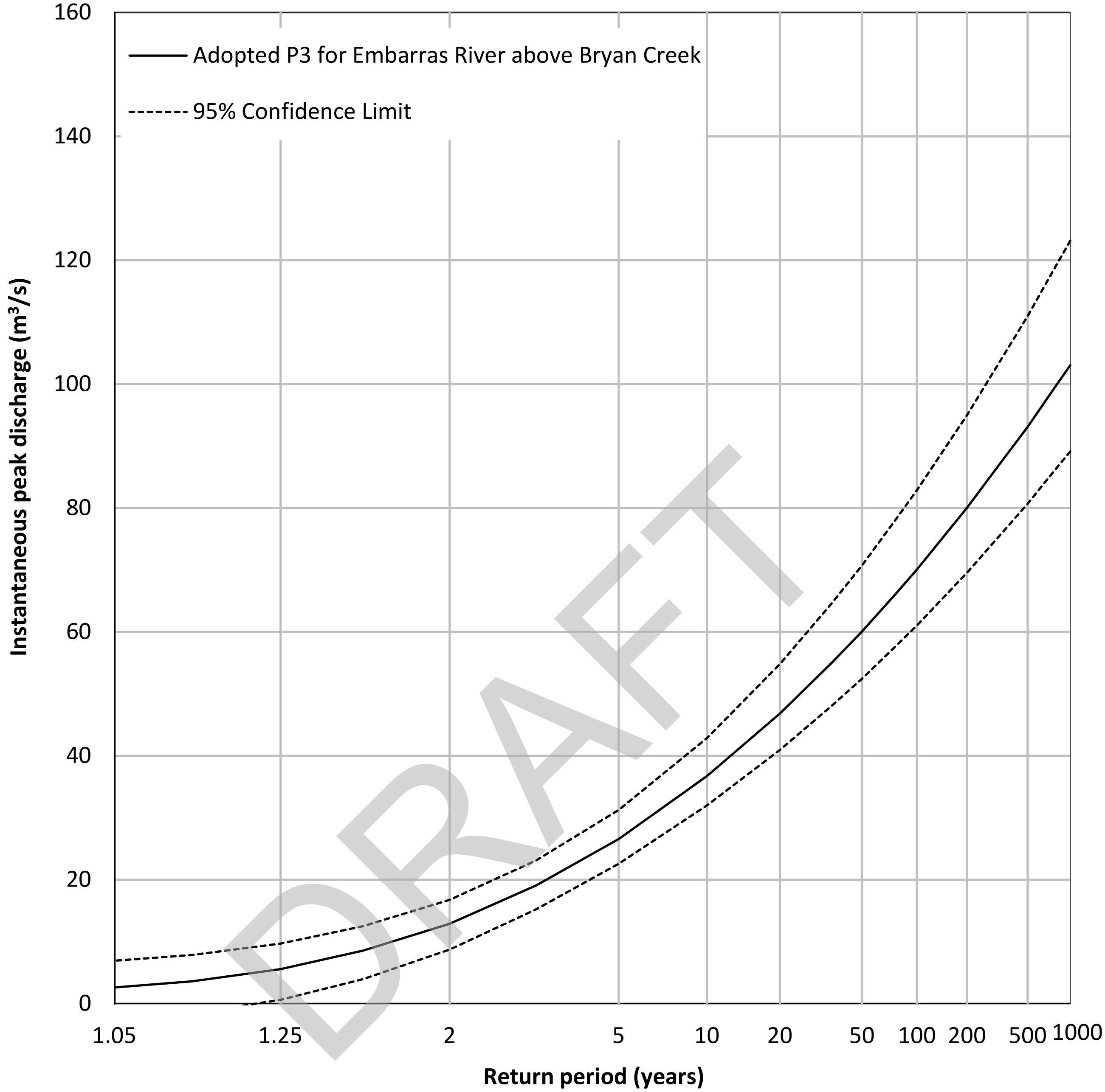
FIGURE 5

6 FLOOD FREQUENCY ESTIMATES

Flood frequency estimates were calculated for 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water flood events at the three selected flood frequency estimate locations along the study reaches. These estimates were derived using the normalized P3 curve from Figure 4 and the relationship between mean peak discharge and drainage area shown in Figure 5. The results are presented in Table 4, while the corresponding flood frequency curves, including confidence limits for each flood frequency estimate location, are presented in Figure 6, 7, and 8.

Table 4: Flood frequency estimates from regional analysis

Return Period (years)	Peak Instantaneous Discharge (m^3/s)					
	Embarras River above Bryan Creek		Embarras River at downstream study boundary		Bryan Creek at the mouth	
	Value	Upper 95% Limit	Value	Upper 95% Limit	Value	Upper 95% Limit
		Lower 95% Limit		Lower 95% Limit		Lower 95% Limit
1000	103.0	123.1	132.5	158.3	28.2	33.8
		89.1		114.6		24.4
750	99.0	118.2	127.3	151.9	27.1	32.4
		85.7		110.2		23.5
500	93.1	111.0	119.7	142.7	25.5	30.4
		80.7		103.7		22.1
350	88.2	104.9	113.3	134.9	24.2	28.8
		76.5		98.3		21.0
200	80.0	95.0	102.8	122.1	21.9	26.0
		69.5		89.4		19.1
100	70.0	82.8	90.0	106.5	19.2	22.7
		61.0		78.4		16.7
75	66.0	78.0	84.9	100.2	18.1	21.4
		57.6		74.0		15.8
50	60.1	70.7	77.2	90.9	16.5	19.4
		52.4		67.4		14.4
35	55.0	64.6	70.7	83.0	15.1	17.7
		48.0		61.8		13.2
20	46.8	54.8	60.2	70.4	12.8	15.0
		40.9		52.6		11.2
10	36.7	42.9	47.2	55.1	10.1	11.8
		32.0		41.1		8.8
5	26.6	31.2	34.2	40.2	7.3	8.6
		22.6		29.0		6.2
2	12.9	16.8	16.6	21.6	3.5	4.6
		8.7		11.2		2.4



SCALE – AS SHOWN

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Units: As Shown

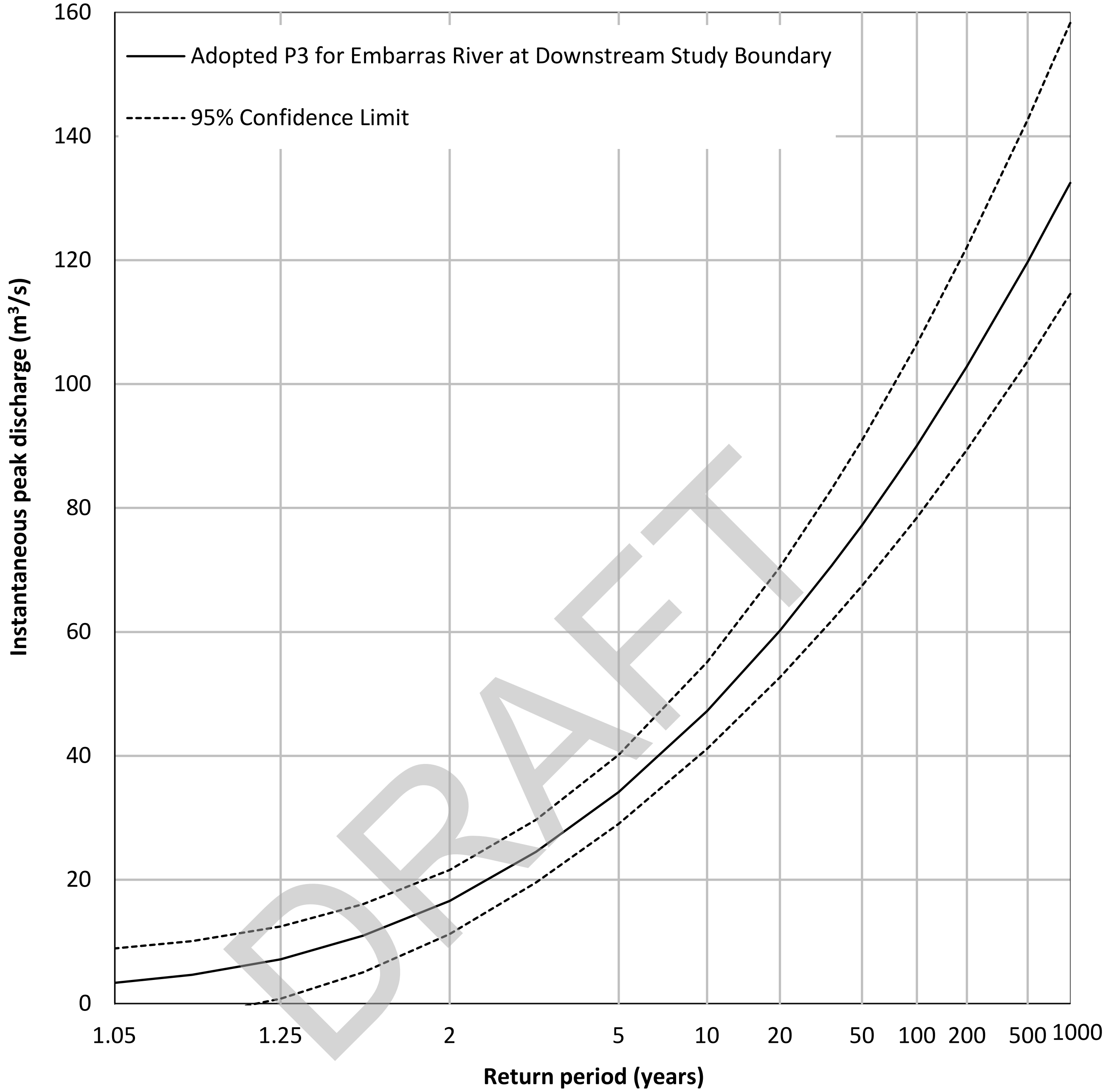
Job: 1009252

Date: 27-FEB-2025

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVE FOR EMBARRAS RIVER ABOVE BRYAN CREEK

FIGURE 6



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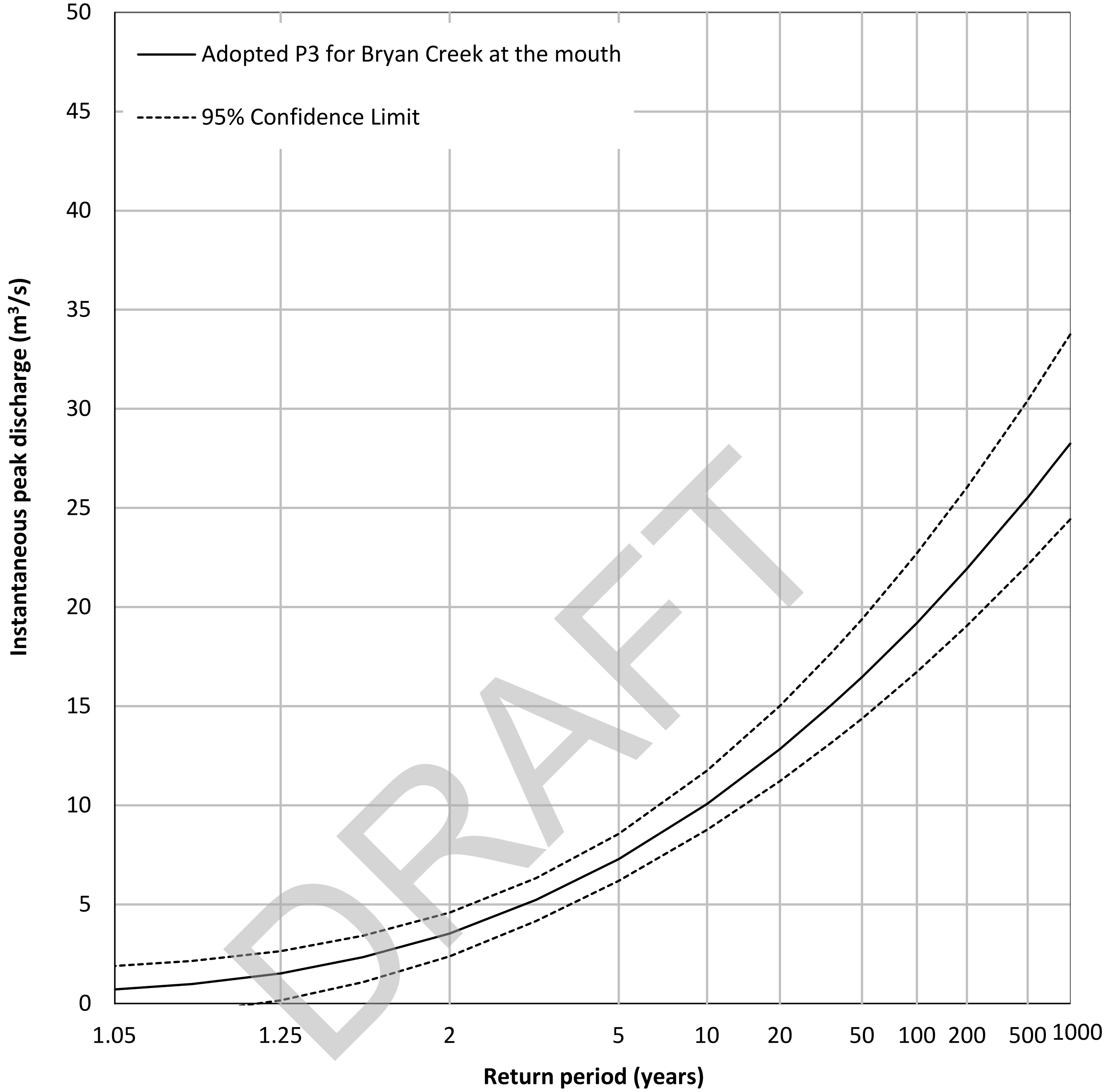
Job: 1009252 | *Date: 27-FEB-2025*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVE FOR EMBARRAS RIVER AT DOWNSTREAM STUDY BOUNDARY

FIGURE 7



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
nhc	Coordinate System: Units: As Shown	**FLOOD FREQUENCY CURVE FOR BRYAN CREEK AT THE MOUTH**
	Job: 1009252 | *Date: 27-FEB-2025*	FIGURE 8

7 COMPARISON WITH PREVIOUS STUDIES

Flood frequency estimates from the current regional analysis for the Embarras River above Bryan Creek are compared with those from a previous study conducted by Alberta Environment (AENV), 1984 in Table 5. Additionally, flood frequency estimates for the Embarras River and Bryan Creek at Robb, calculated by Associated (2001), are also included in Table 5 for comparison. Notably, there is no existing provincial flood hazard mapping for the Hamlet of Robb, and none of these prior flood frequency estimates were linked to detailed flood mapping based on provincial guidelines and standards.

Table 5: Comparison with previous flood frequency estimates

Return Period (years)	Embarras River above Bryan Creek			Bryan Creek at the mouth		
	This Study	AENV (1984)	Associated (2001)	This Study	AENV (1984)	Associated (2001)
	Drainage Area (km^2)					
	122	123	125	24.2		26
	Peak Instantaneous Discharges (m^3/s)					
200	80.0	95.8		21.9		
100	70.0	82.7	158	19.2		33
50	60.1	67.6		16.5		
20	46.8	52.7		12.8		
10	36.7	40.0		10.1		
5	26.6	27.8		7.3		
2	12.9	12.6		3.5		

The current study generally provides lower flood peak estimates for the Embarras River above Bryan Creek compared to the AENV (1984) study, except for the 2-year flood. The difference in peak flood estimates between the two studies range from 2% to 16%, depending on the return period. These discrepancies primarily attributed from differences in the selection of gauging stations for regional analysis. The AENV (1984) study relied on three gauging stations: WSC Station 05AF005 (Eunice Creek near Hinton), WSC Station 05DD008 (Cardinal River near the mouth), and WSC Station 07AF002 (McLeod River above Embarras River). Among these, the Cardinal River basin is not homogeneous with the study basins because a significant portion of it is in the Rocky Mountain region. Similarly, the McLeod River basin, with a drainage area of 2,552 km^2, is more than 15 times larger than the study basin, making it unrepresentative of the hydrological conditions in the study area. The selections of regional stations in AENV (1984) were likely influenced by the limited availability of regional gauges prior to 1984.

The current study benefited from the inclusion of five additional gauges that are more homogeneous with the study basins. It also utilized longer flow records and incorporated recent events such as the 2023 flood (as available). These enhancements reduced uncertainties and improved the reliability of the flood frequency estimates in current study compared to the AENV (1984) study.

The differences in 100-year flood frequency estimates between the current study and the Associated (2001) study are more significant. Associated (2001) estimated the 100-year peak as 56% higher for the Embarras River above Bryan Creek and 42% higher for Bryan Creek at the mouth. The Associated study relied solely on data from WSC Station 07AF004 (Deerlick Creek near Hinton) and prorated the peak discharges to the study basin using a simple drainage area ratio without applying a power factor. Furthermore, using Deerlick Creek, a small basin with a drainage area of just 14.9 km^2, to predict flood flows for the Embarras River basin, which is more than ten times larger, would cause considerable uncertainty in the results. Additionally, the study did not evaluate the P3 distribution, which has, in general, shown to best fit the flood peaks for the region. While Associated (2001) described their estimates as "conservative high," these values are overly conservative and not applicable for this flood mapping study.

Overall, the differences between the current and previous studies reflect the impact of updated data and improved methodologies on flood frequency estimates.

8 JUNE 2023 FLOOD PEAK ESTIMATION

The June 2023 flood was a significant event in the region. EPA conducted a survey of highwater marks (HWMs) along the study reaches for this flood. While the June 2023 flood could serve as a calibration event for hydraulic modeling, no flow measurements were available. To address this gap, several methods can be used to estimate the peak flows for the June 2023 flood. This report presents the flood peak estimation based on regional hydrological analysis, while additional methods and adopted calibration flow details are provided in the main study summary report.

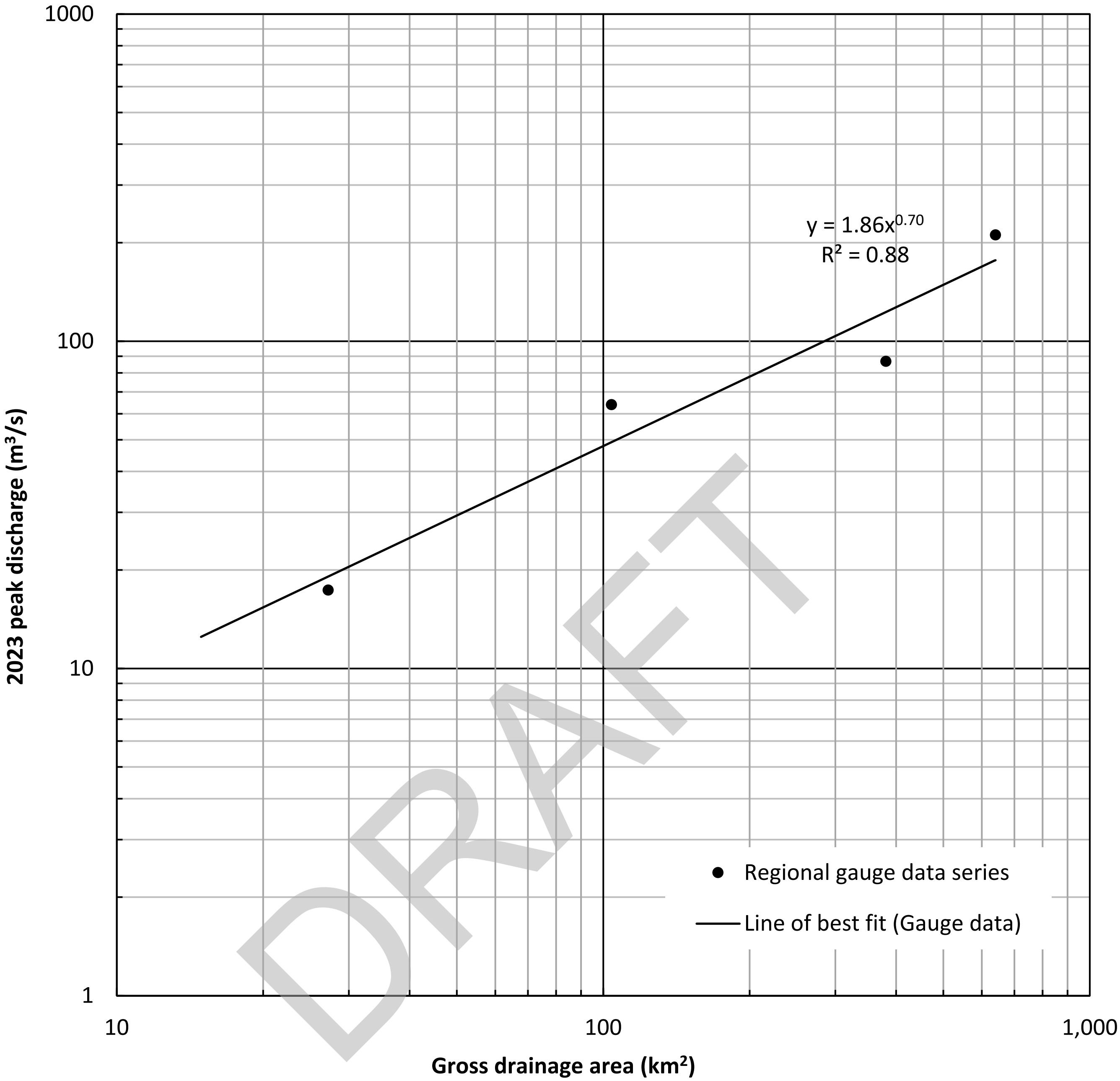
The peak flow data for the 2023 flood are available from four regional stations out of the six included in the regional analysis (Section 4). The regional stations with 2023 flood peak data are as follows:

- WSC Station 07AF003 – Wampus Creek near Hinton (drainage area 27.2 km^2)
- WSC Station 07BA003 – Lovett River near the Mouth (drainage area 104 km^2)
- WSC Station 07AF015 – Gregg River near the Mouth (drainage area 381 km^2)
- WSC Station 07AF014 – Embarras River near Weald (drainage area 640 km^2)

Figure 9 shows the relationship between the 2023 flood instantaneous peak discharges (Q_{i2023}) and drainage areas for the above selected regional stations. It shows that the peak discharge is proportional to the drainage area to the power of 0.70. Table 6 shows the 2023 peak discharges for the flood frequency estimate sites computed with the relationship shown in Figure 9.

Table 6: Computed 2023 peak discharges for flood frequency estimate sites

Flood Frequency Estimate Location	Gross Drainage Area (km^2)	2023 Flood Peak (m^3/s)
Embarras River above Bryan Creek	122	54
Embarras River at downstream study boundary	167	67
Bryan Creek at the mouth	24.2	17



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ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

RELATIONSHIP BETWEEN 2023 PEAK DISCHARGE AND DRAINAGE AREA

FIGURE 9

9 CLIMATE CHANGE COMMENTARY

This section summarizes current knowledge on projected climate and hydrologic changes that may affect future flooding within the project study area. Understanding these potential changes is important for anticipating and managing future flood risks. To date, hydrologic projections, such as future streamflows and climate variables, are not specifically available for the Embarras River and Bryan Creek watersheds. However, studies from nearby headwater streams with similar characteristics are reviewed to help identify the likely direction of future hydrologic changes in these watersheds.

This section is organized as follows:

- Section 9.1 presents climate projections for the Upper McLeod River Basin, to which Embarras River and Bryan Creek are tributaries.
- Section 9.2 discusses the uncertainty associated with climate projections.
- Section 9.3 describes potential future hydrologic changes.
- Section 9.4 reviews studies of climate change in the neighboring Upper Athabasca River Basin above Hinton.
- Section 9.5 summarizes the conclusions of this climate change assessment.

9.1 Climatic Projections for the Upper McLeod River Basin

Climate projections for various Canadian watersheds are available from the climate data portal of ClimateData.ca[1], which is supported by the Canadian Centre for Climate Services (CCCS), Environment and Climate Change Canada (ECCC). These projections are obtained by running numerical models of the earth's climate, known as global climate models (GCMs). They used an ensemble of 26 GCMs for the most recent dataset known as CMIP6 (Coupled Model Intercomparison Project 6th Edition). Projections are available for the upper McLeod River Basin upstream of Ansell. The watershed location is shown in Figure 10.

Projections are available for various scenarios of future greenhouse gas emissions (known as "shared socioeconomic pathways", or SSPs). Five different classes of SSPs were developed for CMIP6 (Riahi et al., 2017). Four of those have been used by a large number of GCMs in CMIP6. Two of those four SSPs – SSP5-8.5 and SSP3-7.0 – consider completely unregulated and unabated future emissions and were regarded as counter-factual scenarios (Chen et al., 2021; Shiogama et al., 2023). In this study, we consider the remaining two SSPs and summarize their air temperature and precipitation projections. SSP2-4.5 has been argued by different authors as representing the current most likely pathway (Huard et al., 2022; Venmans and Carr, 2024). It is

[1] https://climatedata.ca/explore/variable/?coords=53.48060288665816,-117.41893065140144,9&delta=&dataset=cmip6&geo-select=IACPV&var=prcptot&var-group=precipitation&mora=summer&rcp=ssp245&decade=2040s&sector=watershed&id=801

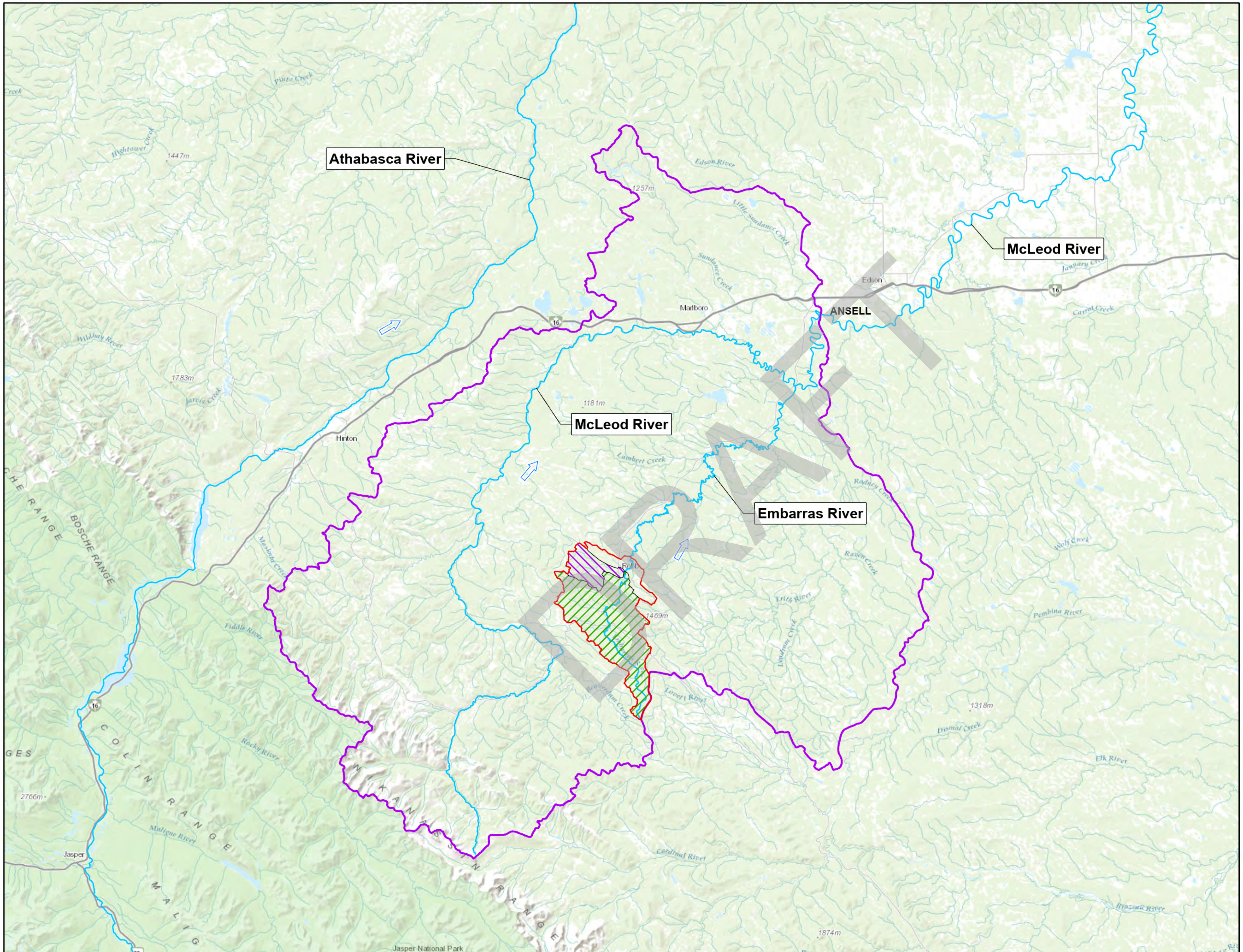
often referred to as a "middle of the road" scenario because of its assumptions about future global greenhouse gas emissions. SSP1-2.6 assumes lower future greenhouse gas emissions and is also considered as a plausible scenario by the same authors (Huard et al., 2022; Venmans and Carr, 2024).

Figure 11 and Figure 12 display the projections of air temperature and precipitation for SSP2-4.5 (in green) and SSP1-2.6 (in blue). These figures indicate that by 2100, the air temperature could rise by up to 3.6°C and precipitation could increase by up to 26 mm, as compared to the reference period 1971-2000. Figure 13 displays the projected number of frost days for SSP2-4.5, the current most likely pathway. The number of frost days is projected to decrease resulting in more precipitation falling as rain rather than snow. The impacts of these changes are discussed further in Section 9.3.

9.2 Uncertainty Associated with Climate Projections

Climate change projections are subject to large and unquantifiable uncertainties. The projections of air temperature and precipitation presented above should therefore be considered as plausible representations of the future, given the best current scientific information, and do not represent specific predictions. Uncertainty is particularly high for precipitation projections.

The main sources of uncertainty are unknown future emissions of greenhouse gases; limitations of current scientific knowledge and the formulation of the climate models used; and the natural variability of climate, in particular the great variability of precipitation from year to year and at longer time scales. The spatial downscaling of the precipitation and temperature time series simulated by the climate models introduces additional uncertainty. Extreme precipitation additionally depends on the local atmospheric concentrations of different types of aerosols, a non-climatic factor.



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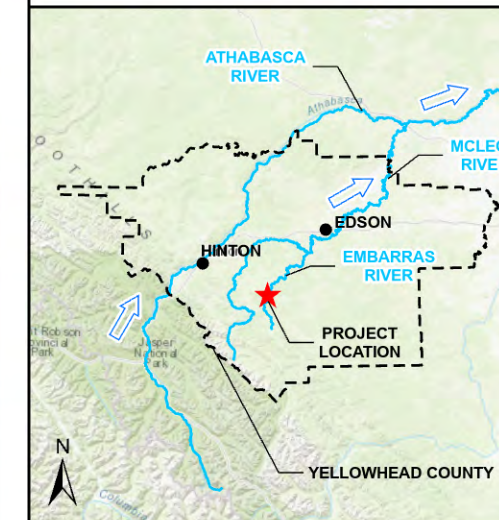

- FLOW DIRECTION
- UPPER MCLEOD RIVER BASIN
- MAJOR RIVER
- EMBARRAS RIVER BASIN ABOVE BRYAN CREEK
- BRYAN CREEK BASIN AT THE MOUTH
- EMBARRAS RIVER BASIN AT DOWNSTREAM STUDY BOUNDARY

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:500,000

0 5 10 15 KM

N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	LS	PGV

Job Number	Date
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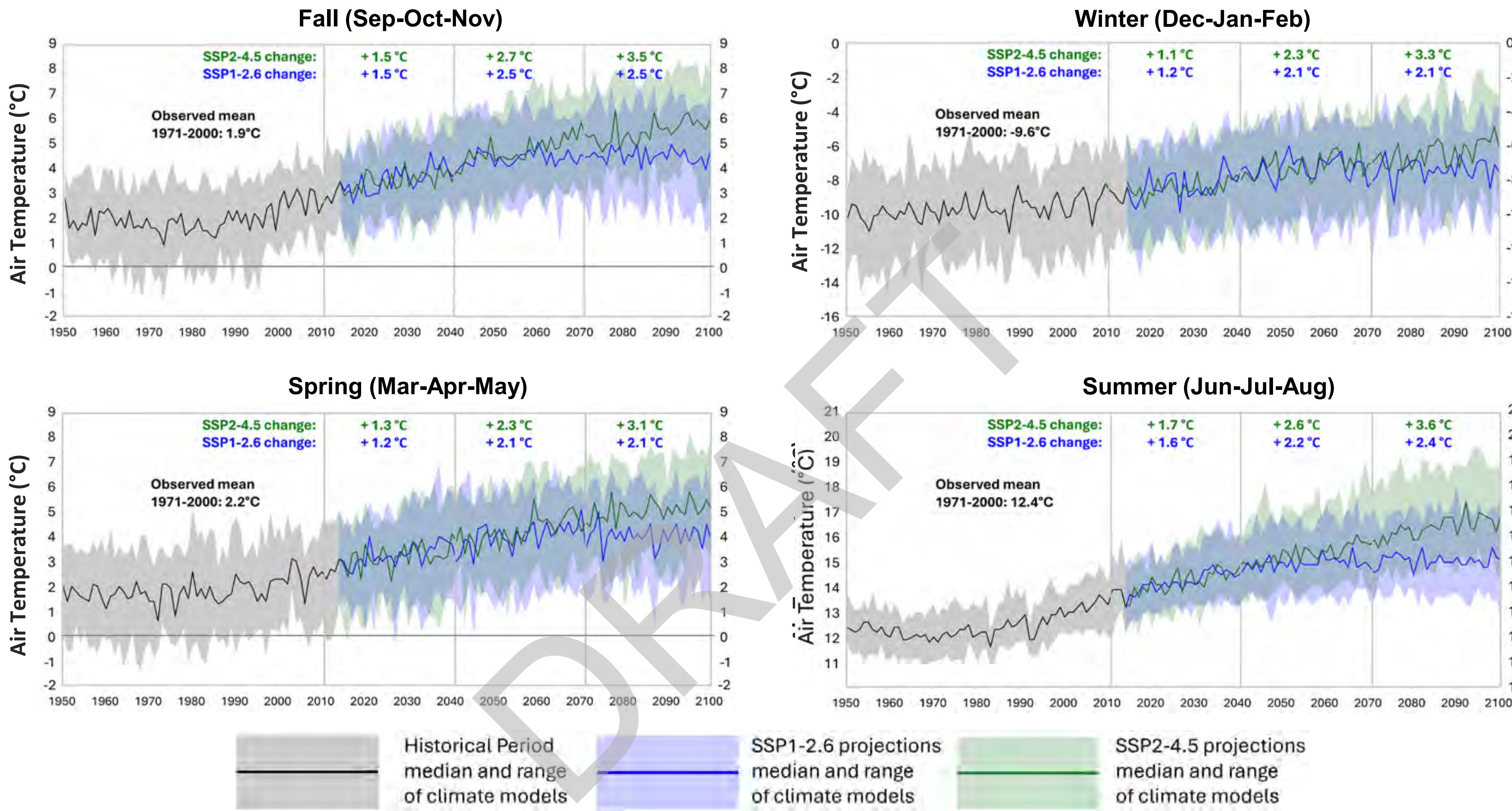
UPPER MCLEOD RIVER BASIN

FIGURE 10

Classification: Public



Notes:
1. Source of data plotted: Climatedata.ca, for the upper McLeod River basin.
2. The values annotated are for periods 2011-2040, 2041-2070 and 2071-2100, relative to 1971-2000.
3. The solid lines indicate the annual averages of the GCM ensembles, while the shaded areas represent the range of results by the different climate models. Black lines and the grey shaded areas represent the GCMs simulations for the historical period where the statistical downscaling process was ensured to be compatible with observations-based estimates

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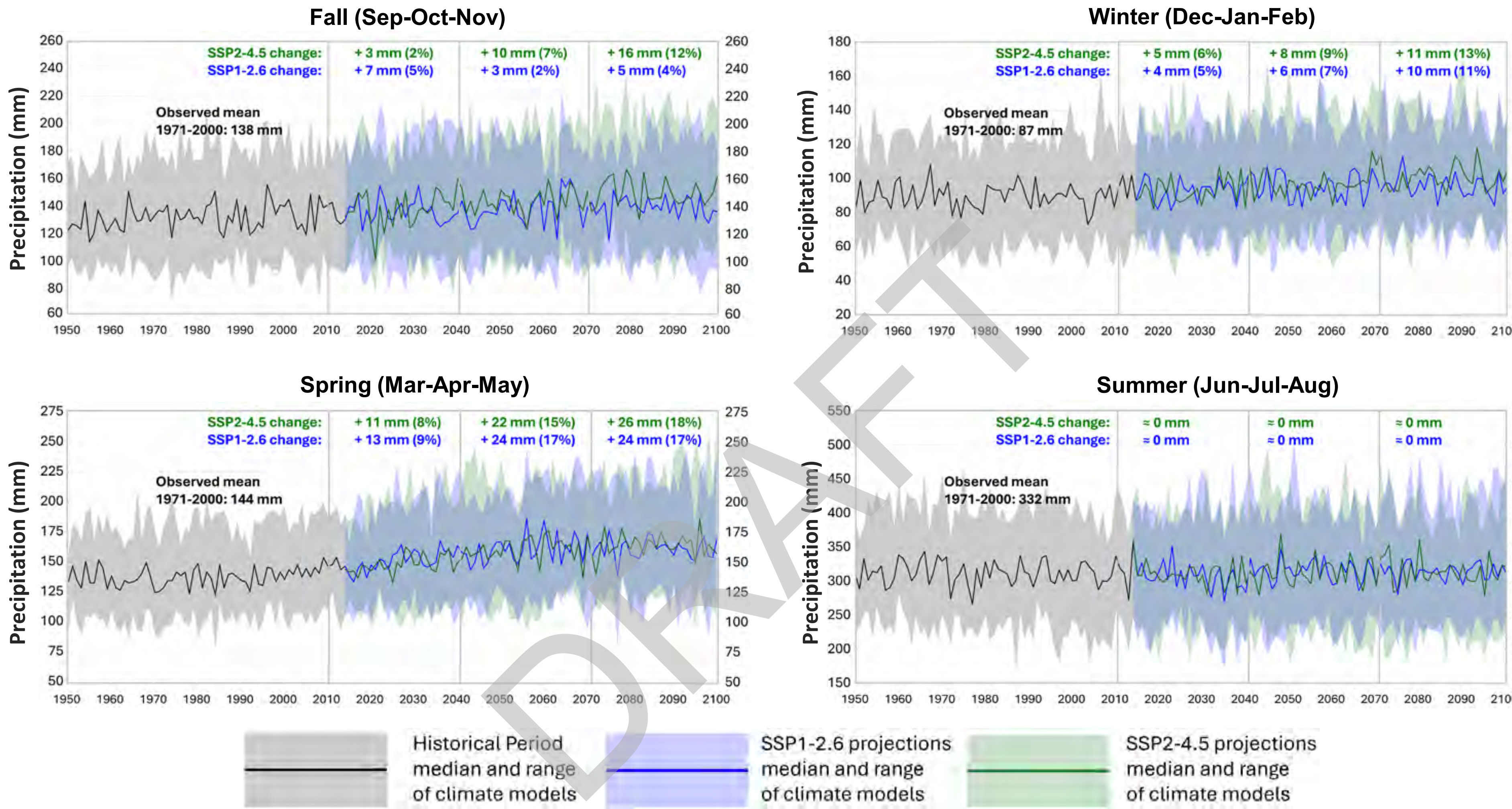
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PROJECTED AIR TEMPERATURE FOR THE UPPER MCLEOD RIVER BASIN

FIGURE 11



Notes:
1. Source of data plotted: Climatedata.ca, for the upper McLeod River basin.
2. The values annotated are for periods 2011-2040, 2041-2070 and 2071-2100, relative to 1971-2000.
3. The solid lines indicate the annual averages of the GCM ensembles, while the shaded areas represent the range of results by the different climate models. Black lines and the grey shaded areas represent the GCMs simulations for the historical period where the statistical downscaling process was ensured to be compatible with observations-based estimates

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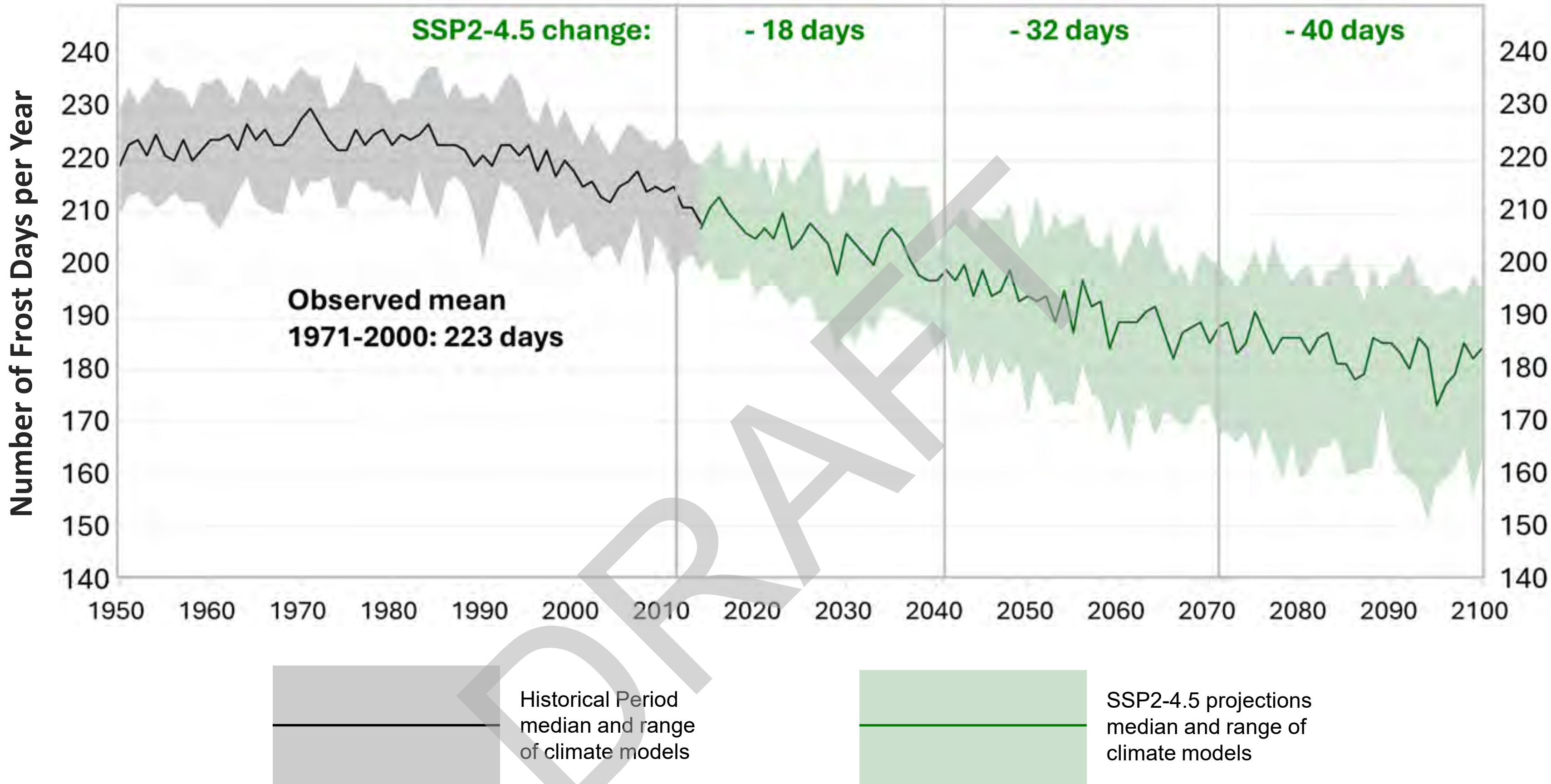
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PROJECTED PRECIPITATION FOR THE UPPER MCLEOD RIVER BASIN

FIGURE 12



Notes:
1. Source of data plotted: Climatedata.ca, for the upper McLeod River basin.
2. The values annotated are for periods 2011-2040, 2041-2070 and 2071-2100, relative to 1971-2000.
3. The solid lines indicate the annual averages of the GCM ensembles, while the shaded areas represent the range of results by the different climate models. Black lines and the grey shaded areas represent the GCMs simulations for the historical period.

Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT **PROJECTED FROST DAYS (SSP2-4.5) FOR THE UPPER MCLEOD RIVER BASIN**
nhc	Coordinate System: Units: As Shown	
	Job: 1009252 *Date: 02-May-2025*	FIGURE 13

9.3 Future Hydrologic Changes

In this section, the direction of future change in peak flow frequency is inferred from the climatic changes projected for each season. While, to our knowledge, hydrologic projections are not available specifically for the Embarras River and Bryan Creek, they are available in peer-reviewed studies for nearby headwater streams of comparable conditions. Inferred changes for annual maximum flows are also checked against results from such studies (Section 9.4).

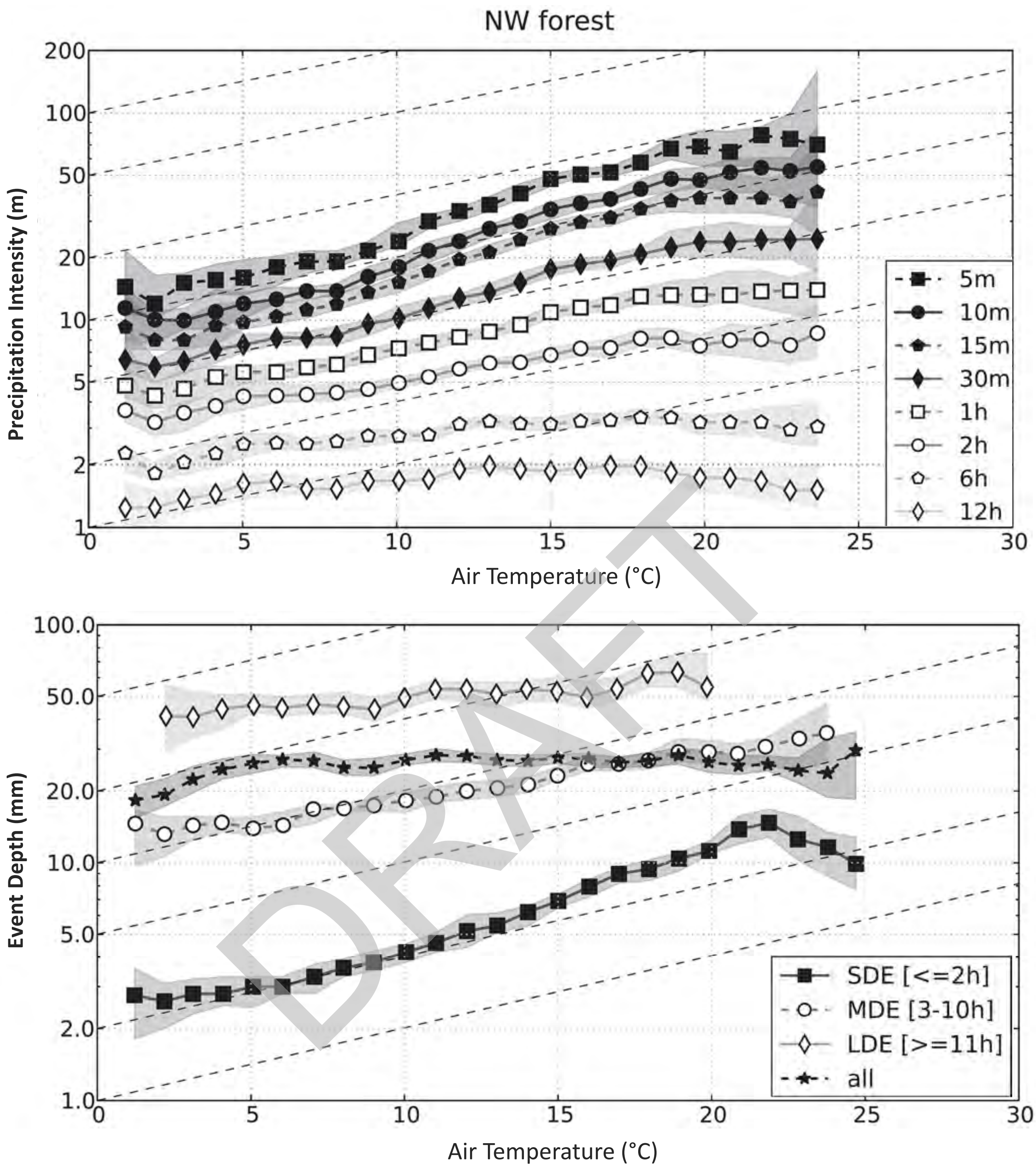
Summer is the season with the most precipitation and most observed annual peak flows in the study basin. The temperature is projected to increase in summer (Figure 11); while the projected total precipitation remains similar (Figure 12). The expected decline in mean annual snow accumulation due to warming will tend to diminish seasonal flows and peak flows. Although no significant change is projected in the total precipitation, the rainfall intensity is likely to increase at sub-daily durations in convective summer storms (described in the following paragraph). The increased rainfall intensity can translate into higher flow peaks given the short time of concentration for small watersheds like the Embarras River and Bryan Creek.

The intensity of convective rainfall is influenced by thermodynamic and dynamic factors. The thermodynamic factor is that the saturation moisture content is higher in warmer air masses, increasing by about 7% per degree °C of warming. This is known as "Clausius-Clapeyron scaling" (CC scaling). Observations find significant deviations from CC scaling in nature, which are likely due to dynamic factors. Panthou et al. (2014) documented scaling values from station observations across Canada and the northern United States of America. Results for the broad 'Northwest Forest' Canadian region, where the Embarras River is located, are displayed in Figure 14. Short-duration precipitation, a category which is dominated by convective rainfall, exhibits 'super-CC scaling', which Panthou et al. (2014) estimated to be double the CC scaling, or 14% per °C. Longer duration precipitation is associated with large-scale synoptic weather systems and is found to respond weakly to air temperature (sub-CC scaling).

In the fall, there will be fewer occurrences of freezing air temperature (Figure 11 and Figure 13); hence less snowfall, less snow accumulation, and less frequent rain-on-snow events are expected. Nevertheless, an increase in mean seasonal precipitation is projected for the fall (Figure 12), and this could increase fall streamflow peaks, especially if the precipitation increase is caused by a more frequent arrival of atmospheric rivers from the Pacific Ocean, or an intensification in atmospheric river moisture transport across the Rocky Mountains.

In the winter, rain-on-snow events are likely to occur more often due to the air temperature occasionally rising above freezing, consistent with the projected rise in mean air temperature (Figure 11) and decline in the number of frost days (Figure 13). As a result, seasonal winter flows are likely to increase. Mean winter precipitation is also projected to increase (Figure 12).

In the spring, the trend towards earlier snowmelt resulting from the projected warming (Figure 11) and increased precipitation (Figure 12), may increase seasonal flows and peak flows.



Notes:

1. The y-axis is logarithmic. Shaded areas represent the 95% confidence interval. Dashed lines correspond to the 7% increase per °C (approximate Clausius-Clapeyron scaling).
2. Top panel: event duration is given in the legend, in minutes (m) and hours (h)
3. Bottom panel: SDE, MDE and LDE stand for short-, medium and long-duration event. Their durations in hours is indicated on the legend.
4. These figure panels are reproduced from Panthou et al. (2014).

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PRECIPITATION INTENSITY AND DEPTH VS AIR TEMPERATURE (PANTHOU ET AL. 2014)

FIGURE 14

9.4 Review of Studies of the Upper Athabasca River above Hinton

Given the absence of flow projections for the Embarras River or Bryan Creek, studies of the neighbouring watershed of the upper Athabasca River above Hinton are mentioned here. The watershed above Hinton is larger (est. 9,765 km^2) and its headwaters are at much higher elevation in the Rocky Mountains, originating from the Columbia glacier in Jasper National Park, at 3,747 m above mean sea level. This implies a longer freezing season and a larger role played by snow accumulation in the watershed's hydrology. Given these important differences, the numerical values for the Athabasca River above Hinton do not apply to Embarras River or Bryan Creek but may share the same direction of change.

Eum et al. (2017) used the process-based Variable Infiltration Capacity (VIC) hydrologic model to simulate hydrologic projections for the Athabasca River watershed above Hinton. The model was forced by CMIP5 (Coupled Model Intercomparison Project 5th Edition) climatic projections from selected GCMs and emission scenarios RCP4.5 and RCP8.5 (Representative Concentration Pathways) were used that were downscaled to a higher resolution of about 10 km over Canada. RCP4.5 scenario is roughly comparable to SSP2-4.5 for which climatic projections for the Upper McLeod River were presented above. The projections simulated by Eum et al. (2017) indicate that the mean annual flow will be about 3% higher in 2041-2070 compared to the reference period 1971-2000; and it will be 9% higher in 2041-2070 compared to the reference period. The date of maximum annual flow is projected to come on average, 12 days earlier in 2041-2070 and 14 days earlier in 2071-2100, compared to the reference period.

Shrestha et al. (2017) also assessed the effects of climate change on freshwater resources of the Athabasca River basin by using a Soil and Water Assessment Tool (SWAT) and future climate data generated by the Canadian Centre for Climate Modelling and Analysis Regional Climate Model (CanRCM4) with a spatial resolution of about 25 km for RCP4.5 and RCP8.5 emission scenarios. Shrestha et al. (2017) stated that most of the projected increase in precipitation was due to its intensification, rather than an increase in the number of wet days. They estimated that the annual streamflow would increase by approximately 1.4% for every 1% rise in annual precipitation due to precipitation intensification. This indicates the potential for higher peak flows during rainstorms. However, projected changes in snow accumulation or maximum annual flow were not reported in this manuscript.

Siemens (2019) applied the Snowmelt Runoff Model (SRM) to project climate change impacts on future runoff in the Athabasca River at Hinton. The projection period was centred on 2070-2080, and four different climate change scenarios were examined to capture uncertainties in climate change projections. The results demonstrated a consistent pattern of change in runoff across all scenarios, with minor increases over winter months, but significant increases in spring runoff and decreases in summer runoff –reflecting the declining snow accumulation and earlier snowmelt timing. The trend analysis study conducted by Rood et al. (2015) on streamflow observed for the Athabasca River basin above Hinton, found increasing trend in winter discharge but decreasing trend in summer discharge.

9.5 Conclusions of Climate Change Assessment

Based on the evidence reviewed, which included climatic projections and the future hydrologic changes that can be inferred from them, as well as existing hydrologic projections for the Upper Athabasca River above Hinton, conclusions can be drawn for possible trends in seasonal flows, but are less clear for seasonal peak flows. The seasonal flows are projected to increase in fall, winter, and spring. This trend is driven by the projected increase in precipitation and progressive increase in the rain-to-snow ratio due to warming.

Summer peak flows have historically represented the majority of the maximum annual flows. The future projections of summer peak flows appear to have more uncertainty. Due to large differences in watershed elevations, the hydrologic projections for the Upper Athabasca River above Hinton (reviewed in Section 9.4) do not readily apply to the Embarras River. Additionally, the studies reviewed did not provide specific projections to summer peak flows. However, Panthou et al. (2014) stated that the convective rainfall rates are expected to increase by more than 7% per one degree °C of warming. This increase in rainfall intensity may lead to higher peak flows, particularly in small watersheds like the Embarras River and Bryan Creek.

It appears possible that, in the upcoming decades, there will continue to be some years with large snow accumulation where the combination of rapid snowmelt with intense rain on snow events could produce very large spring/early summer flow peaks. Later, as warming progresses further, it appears likely that large snow accumulations will become rare or will no longer occur. Therefore, the possibility of a temporary increase in peak flows followed by a decline in peak flows later this century is plausible, but it is not possible to conclude that with certainty.

Finally, an increasing risk of wildfires represents a secondary effect of the projected warming that could impact flow peaks (e.g., Jain et al., 2022; Romero-Cuellar et al., 2025). Very low nighttime temperatures play an important role in controlling the growth of western pine beetle. Warming implies a growing risk of forest infestations and tree death, providing fuel for wildfires. Post-fire soils can also have low permeability, thereby generating higher runoff peaks during rainstorms.

CLOSURE

We trust this report meets your needs. If you have any questions or requests, please feel free to contact the undersigned at (780) 436-5868.

Sincerely,
Northwest Hydraulic Consultants Ltd.

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APEGA Permit to Practice Number: P654

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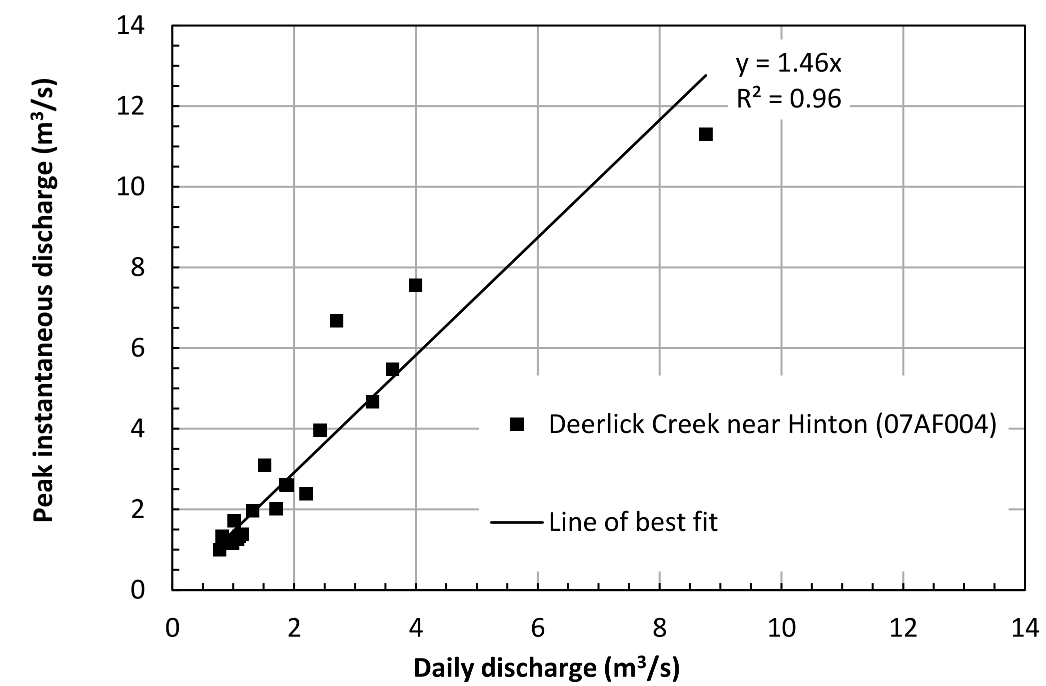
Appendix A

Flow Data Used for Regional Analysis

07AF004 – Deerlick Creek near Hinton

Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on Same Event of Peak Instantaneous Discharge (m^3/s)
1967	2.01	09-Jun	1.71	09-Jun	
1968	1.38	22-Jul	1.15	22-Jul	
1969	11.90	05-Aug	3.06	05-Jul	N/A
1970	3.09	16-Jun	1.52	16-Jun	
1971	2.39	09-Jun	2.20	09-Jun	
1972	2.60	25-Jun	1.89	25-Jun	
1973	1.21	16-May	0.91	16-May	
1974	1.26	06-May	1.08	06-May	
1975	**<u>1.07</u>**		0.73	09-May	
1976	**<u>1.27</u>**		0.87	01-May	
1977	3.96	29-May	2.44	22-May	2.43
1978	**<u>2.60</u>**		1.78	16-May	
1979	1.33	20-Jun	0.82	20-Jun	
1980	11.30	04-Jun	8.76	04-Jun	
1981	1.16	30-Jul	1.00	30-Jul	
1982	5.47	04-Jul	3.62	05-Jul	
1983	1.00	24-Jun	0.78	24-Jun	
1984	1.33	08-Jun	1.10	08-Jun	
1985	1.96	12-Sep	1.44	15-Aug	1.32
1986	7.56	17-Jul	4.00	17-Jul	
1987	6.68	01-Aug	2.70	01-Aug	
1988	1.72	08-Jun	1.02	08-Jun	
1989	2.61	16-Aug	1.86	17-Aug	
1990	4.67	13-Jun	3.29	13-Jun	



Notes: 1. The bolded and underlined values are based on Qi=1.46Qd.

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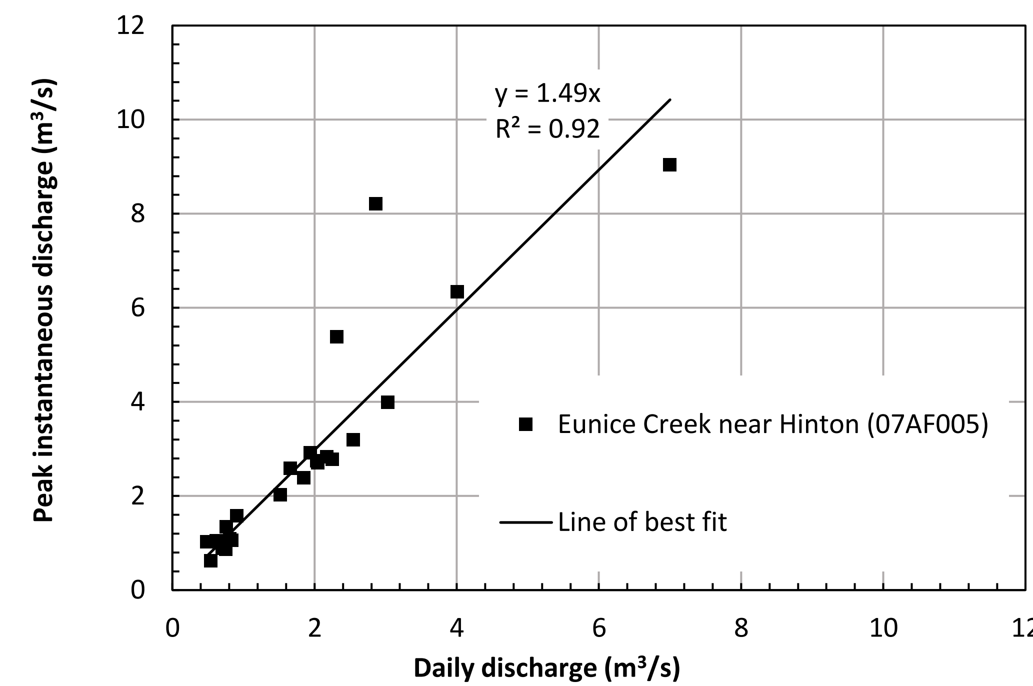
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
DEERLICK CREEK NEAR HINTON MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-1

Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on Same Event of Peak Instantaneous Discharge (m^3/s)
1968	1.04	20-Jul	0.77	22-Jul	0.62
1969	8.21	05-Aug	2.86	05-Aug	
1970	2.59	16-Jun	1.66	16-Jun	
1971	2.78	08-Jun	2.25	09-Jun	
1972	2.83	25-Jun	2.17	25-Jun	
1973	2.70	16-May	2.05	16-May	
1974	1.06	06-May	0.84	07-May	
1975	1.03	08-May	0.49	09-May	
1976	0.62	16-Jun	0.54	16-Jun	
1977	2.92	29-May	1.94	29-May	
1978	2.75	16-May	2.03	16-May	
1979	1.34	20-Jun	0.76	20-Jun	
1980	9.04	04-Jun	7.00	04-Jun	
1981	0.87	30-Jul	0.76	30-Jul	
1982	3.99	04-Jul	3.03	05-Jul	
1983	0.89	24-Jun	0.71	24-Jun	
1984	0.89	08-Jun	0.74	08-Jun	
1985	1.09	15-Aug	0.90	13-Sep	0.81
1986	6.34	17-Jul	4.01	18-Jul	
1987	5.38	01-Aug	2.31	02-Aug	
1988	1.58	08-Jun	0.91	08-Jun	
1989	2.02	16-Aug	1.56	10-Jul	1.52
1990	3.19	13-Jun	2.55	13-Jun	
1991	2.38	09-May	2.04	13-May	1.85
1992	**<u>0.48</u>**		0.32	27-May	

07AF005 – Eunice Creek near Hinton



Notes: 1. The bolded and underlined values are based on Qi=1.49Qd.

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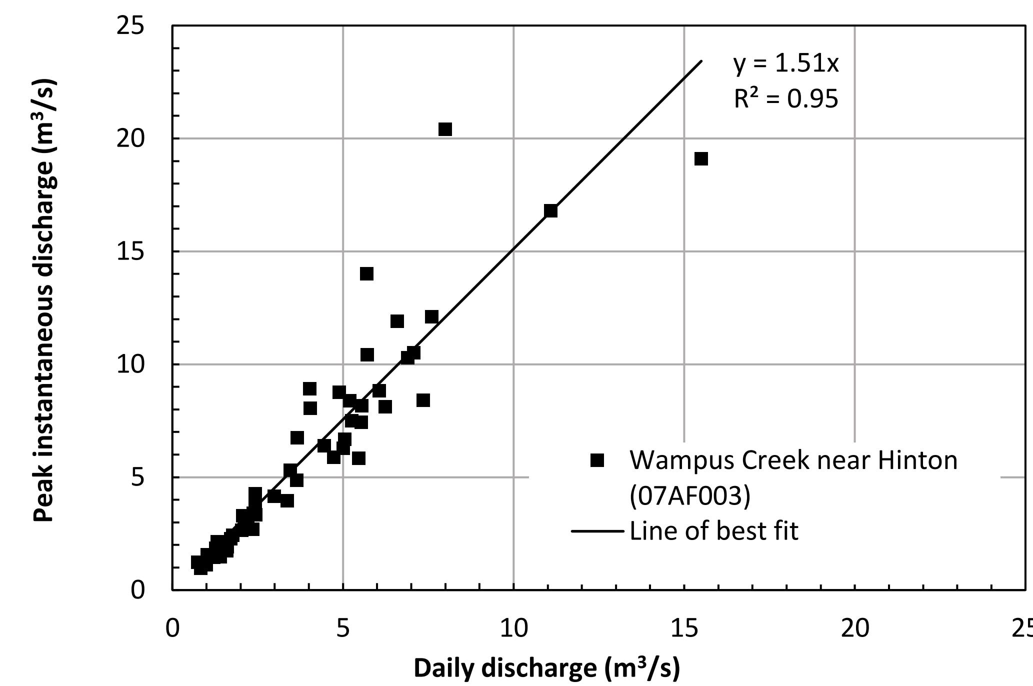
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

EUNICE CREEK NEAR HINTON
MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-2

Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on Same Event of Peak Instantaneous Discharge (m^3/s)
1967	**3.97**		2.63	09-Jun	
1968	2.13	20-Jul	1.56	22-Jul	1.32
1969	20.40	05-Aug	7.99	05-Aug	
1970	3.94	16-Jun	3.37	16-Jun	
1971	7.50	08-Jun	5.27	09-Jun	
1972	10.30	25-Jun	6.91	25-Jun	
1973	8.38	15-May	5.21	16-May	
1974	2.42	06-May	1.78	06-May	
1975	0.95	17-Jun	0.85	09-May	0.84
1976	1.45	03-May	1.22	02-May	
1977	8.75	29-May	4.90	29-May	
1978	8.04	16-May	4.05	16-May	
1979	1.57	20-Jun	1.10	16-May	1.03
1980	19.10	04-Jun	15.50	04-Jun	
1981	3.34	30-Jul	2.45	30-Jul	
1982	7.43	04-Jul	5.55	05-Jul	
1983	1.85	24-Jun	1.28	24-Jun	
1984	2.26	04-Oct	1.71	04-Oct	
1985	3.06	15-Aug	2.13	15-Aug	
1986	11.90	17-Jul	6.59	17-Jul	
1987	8.92	01-Aug	4.03	02-Aug	
1988	3.28	08-Jun	2.07	08-Jun	
1989	6.29	16-Aug	5.01	17-Aug	
1990	8.11	13-Jun	6.24	13-Jun	
1991	5.30	09-May	3.46	09-May	
1992	1.24	29-May	0.75	30-May	
1993	**1.80**		1.19	24-Jun	
1994	6.73	17-Aug	3.67	17-Aug	
1995	5.87	08-Aug	4.74	08-Aug	
1996	5.85	01-Jun	5.46	01-Jun	
1997	3.39	23-Jun	2.38	24-Jun	
1998	4.85	16-May	3.93	29-Jun	3.64
1999	16.80	03-Jul	11.10	03-Jul	
2000	2.12	15-May	1.60	16-May	
2001	2.64	25-Jul	2.04	25-Jul	
2002	1.91	20-May	1.61	20-May	
2003	**3.02**		2.00	12-May	
2004	4.26	11-Jul	2.43	11-Jul	
2005	10.50	10-Sep	7.43	18-Jun	7.08
2006	3.41	15-Jun	2.39	16-Jun	
2007	2.69	06-Jun	2.36	06-Jun	
2008	6.67	07-Jun	5.05	07-Jun	
2009	1.45	09-Jul	1.18	09-Jul	
2010	1.48	10-Jun	1.41	10-Jun	
2011	12.10	17-Jun	7.60	17-Jun	
2012	8.82	09-Jun	6.07	09-Jun	
2013	6.39	21-Jun	4.46	21-Jun	
2014	1.74	19-May	1.60	18-May	
2015	1.11	09-May	1.00	10-May	
2016	14.00	06-Aug	5.70	06-Aug	
2017	3.67	10-Jun	3.17	13-May	2.43
2018	8.15	04-Jul	5.56	04-Jul	
2019	8.41	21-Jun	7.36	21-Jun	
2020	10.40	01-Jul	5.72	02-Jul	
2021	4.15	01-Sep	3.00	01-Sep	
2022	3.22	24-Jun	2.21	24-Jun	
2023	**17.37**		11.50	20-Jun	
2024	1.96	28-Jun	1.34	28-Jun	

07AF003 – Wampus Creek near Hinton



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Notes: 1. The bolded and underlined values are based on Qi=1.51Qd.
2. Data for 2024 is preliminary from WSC.

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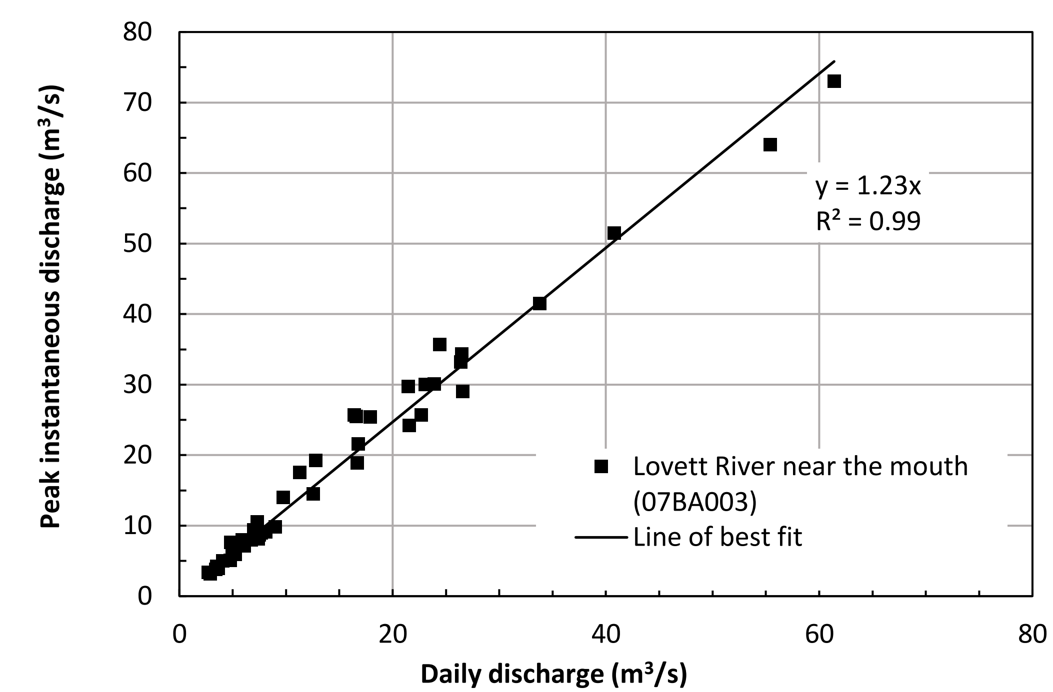
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

WAMPUS CREEK NEAR HINTON MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-3

Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on Same Event of Peak Instantaneous Discharge (m^3/s)
1975	3.34	10-May	2.76	29-Jun	2.7
1976	3.62		2.94	24-Jun	
1977	9.15	01-Jun	8.13	01-Jun	
1978	14.00	15-May	10.40	12-Jul	9.8
1979	**3.20**		2.60	24-May	
1980	73.00	04-Jun	61.40	04-Jun	
1981	9.83	30-Jul	9.01	30-Jul	
1982	29.00	05-Jul	26.60	05-Jul	
1983	4.19	24-Jun	3.74	21-Jun	3.5
1984	2.87	08-Jun	2.55	08-Jun	
1985	8.94	13-Sep	7.71	13-Sep	
1986	51.50	18-Jul	40.80	18-Jul	
1987	25.40	02-Aug	17.90	02-Aug	
1988	6.29	09-Jun	4.97	09-Jun	
1989	14.50	17-Aug	12.60	17-Aug	
1990	25.70	13-Jun	22.70	13-Jun	
1991	19.20	06-Jul	13.60	13-May	12.8
1992	**2.95**		2.40	28-Apr	
1993	**4.50**		3.66	24-Jun	
1994	7.64	17-Aug	5.63	05-Jul	4.9
1995	35.70	08-Aug	24.40	08-Aug	
1996	29.70	01-Jun	21.50	01-Jun	
1997	**6.30**		5.12	23-Jun	
1998	21.60	02-Jul	16.80	02-Jul	
1999	30.10	15-Jul	23.90	15-Jul	
2000	5.01	11-Jun	4.08	12-Jun	
2001	10.50	25-Jul	7.33	26-Jul	
2002	3.15	28-May	2.93	28-May	
2003	3.76	13-May	3.43	13-May	
2004	7.94	11-Jul	5.91	12-Jul	
2005	25.50	18-Jun	16.60	18-Jun	
2006	17.50	16-Jun	11.30	16-Jun	
2007	3.92	17-Jun	3.65	17-Jun	
2008	33.20	07-Jun	26.40	07-Jun	
2009	5.90	09-Jul	5.27	09-Jul	
2010	8.66	10-Jun	7.51	10-Jun	
2011	41.50	17-Jun	33.80	17-Jun	
2012	25.70	09-Jun	16.40	09-Jun	
2013	34.30	21-Jun	26.50	21-Jun	
2014	7.14	29-May	6.10	29-May	
2015	**2.19**		1.78	01-May	
2016	5.06	27-May	4.78	27-May	
2017	9.34	10-Jun	7.54	25-May	7.0
2018	24.20	04-Jul	21.60	04-Jul	
2019	18.90	21-Jun	16.70	21-Jun	
2020	30.00	02-Jul	23.10	02-Jul	
2021	7.98	25-May	6.78	25-May	
2022	**8.79**		7.15	24-Jun	
2023	64.00	20-Jun	55.40	20-Jun	
2024	8.10	22-May	7.58	26-May	7.4

07BA003 – Lovett River near the mouth



Notes: 1. The bolded and underlined values are based on Qi=1.23Qd.
2. Data for 2024 is preliminary from WSC.

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Coordinate System:
Units: As Shown

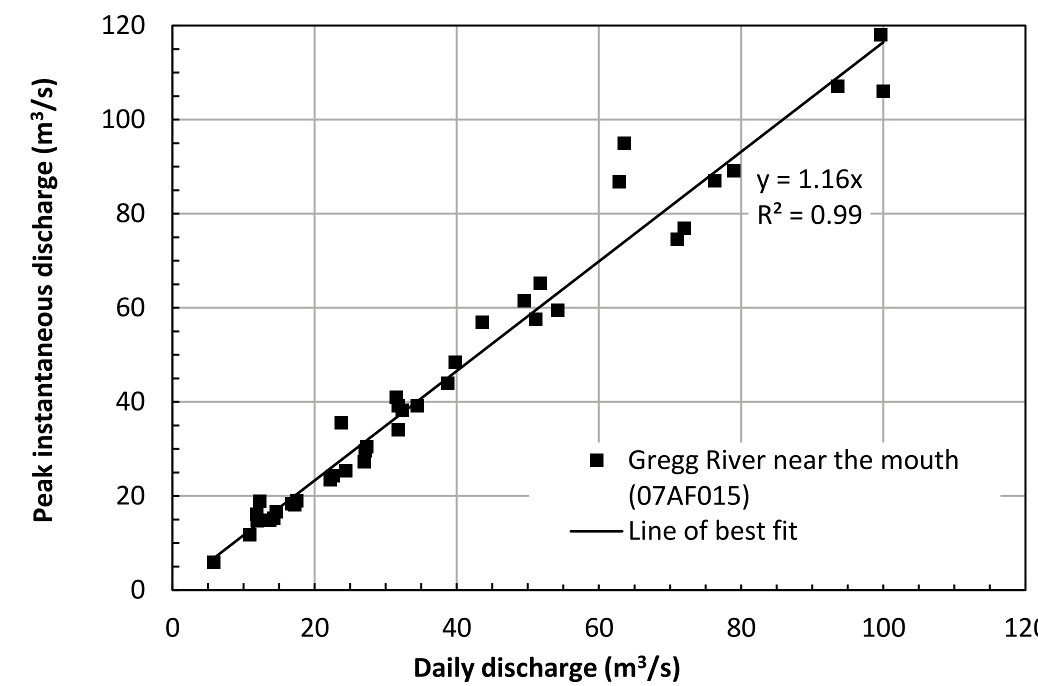
Job: 1009252 | Date: 03-OCT-2024

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
LOVETT RIVER NEAR THE MOUTH MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-4

Year	Peak Instantaneous Discharge (m³/s)	Date	Peak Daily Discharge (m³/s)	Date	Daily Discharge on Same Event of Peak Instantaneous Discharge (m³/s)
1985	23.40	13-Sep	22.20	13-Sep	
1986	107.00	18-Jul	93.60	18-Jul	
1987	89.10	02-Aug	79.00	02-Aug	
1988	16.10	09-Jun	11.90	09-Jun	
1989	74.60	17-Aug	71.00	17-Aug	
1990	59.40	07-Jul	54.20	07-Jul	
1991	34.10	13-May	31.80	13-May	
1992	15.20	27-May	14.30	27-May	
1993	**14.96**		12.90	10-Jul	
1994	18.90	17-Aug	16.80	05-Jul	12.3
1995	61.50	08-Aug	49.50	09-Aug	
1996	48.40	31-May	39.80	31-May	
1997	39.20	24-Jun	35.10	12-Jul	34.5
1998	43.90	03-Jul	38.80	03-Jul	
1999	87.00	03-Jul	76.30	04-Jul	
2000	30.40	11-Jun	27.40	11-Jun	
2001	41.00	25-Jul	31.50	26-Jul	
2002	16.60	29-May	14.60	29-May	
2003	18.10	26-May	17.20	25-May	
2004	39.20	11-Jul	31.80	12-Jul	
2005	65.20	19-Jun	51.80	19-Jun	
2006	11.70	16-Jun	10.90	16-Jun	
2007	38.20	06-Jun	32.40	06-Jun	
2008	27.30	25-May	27.00	26-May	
2009	24.30	09-Jul	22.60	09-Jul	
2010	14.70	13-Jul	12.00	14-Jul	
2011	106.00	17-Jun	100.00	17-Jun	
2012	95.00	09-Jun	63.60	10-Jun	
2013	118.00	21-Jun	99.70	21-Jun	
2014	14.80	29-May	13.70	29-May	
2015	5.97	24-May	5.83	24-May	
2016	18.30	27-May	16.80	27-May	
2017	29.60	25-May	27.10	25-May	
2018	56.90	04-Jul	43.60	04-Jul	
2019	57.60	28-Jun	51.10	28-Jun	
2020	76.90	02-Jul	72.00	02-Jul	
2021	35.50	01-Sep	23.80	01-Sep	
2022	25.30	16-Jun	24.40	16-Jun	
2023	86.82	20-Jun	62.90	20-Jun	
2024	18.91	26-May	17.49	26-May	

07AF015 – Gregg River near the mouth



Notes: 1. The bolded and underlined values are based on Qi=1.16Qd.
2. Data for 2023-2024 is preliminary from WSC.

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Coordinate System:
Units: As Shown

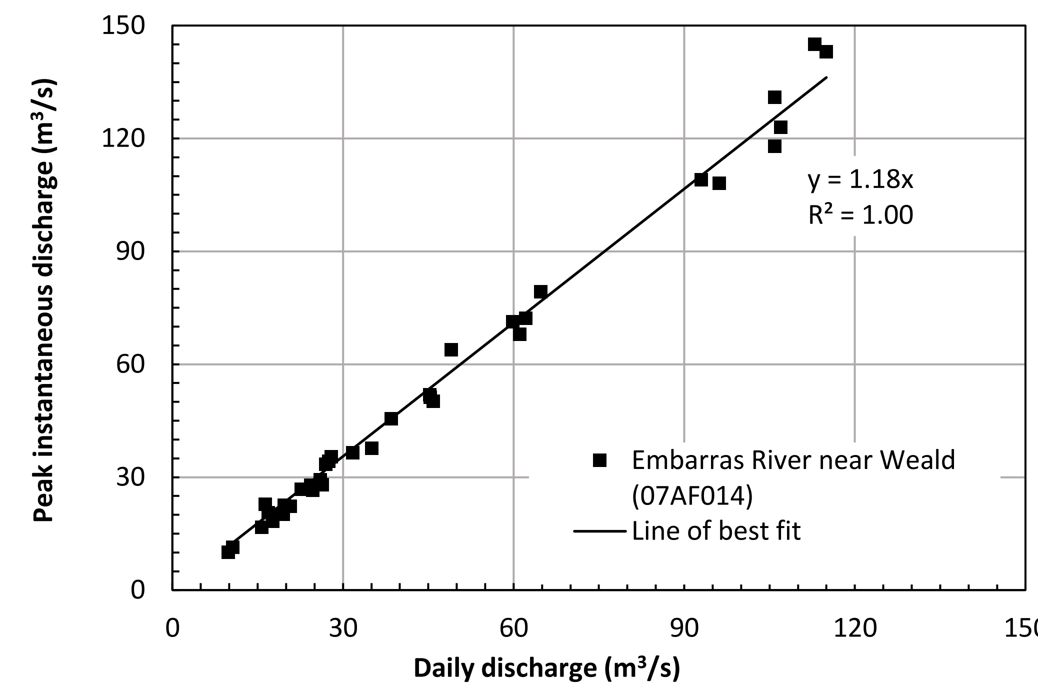
Job: 1009252 Date: 03-OCT-2024

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
GREGG RIVER NEAR THE MOUTH MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-5

Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on Same Event of Peak Instantaneous Discharge (m^3/s)
1984	20.1	22-Sep	19.5	22-Sep	
1985	35.4	13-Sep	28.0	14-Sep	
1986	118.0	18-Jul	106.0	18-Jul	
1987	145.0	02-Aug	113.0	02-Aug	
1988	22.7	09-Jun	19.2	12-Jun	16.4
1989	36.4	17-Aug	31.7	17-Aug	
1990	71.3	13-Jun	59.9	13-Jun	
1991	51.2	10-May	45.4	10-May	
1992	10.1	24-Apr	9.9	24-Apr	
1993	**8.4**		7.2	29-Aug	
1994	33.4	18-Aug	27.0	18-Aug	
1995	131.0	09-Aug	106.0	09-Aug	
1996	109.0	01-Jun	93.0	01-Jun	
1997	68.0	12-Jul	61.1	12-Jul	
1998	50.2	30-Jun	45.9	30-Jun	
1999	143.0	08-Jul	115.0	08-Jul	
2000	37.6	12-Jun	35.1	12-Jun	
2001	51.8	26-Jul	45.3	26-Jul	
2002	16.7	22-May	15.8	22-May	
2003	**41.3**		35.0	26-Apr	
2004	26.6	12-Jul	24.7	12-Jul	
2005	**112.1**		95.0	29-Jun	
2006	45.4	16-Jun	38.5	16-Jun	
2007	26.8	19-Jul	22.7	19-Jul	
2008	79.2	07-Jun	64.8	07-Jun	
2009	28.0	09-Jul	26.4	09-Jul	
2010	20.2	11-Jun	18.1	11-Jun	
2011	**115.6**		98.0	20-Jun	
2012	63.9	09-Jun	49.1	10-Jun	
2013	72.1	26-May	62.2	26-May	
2014	22.2	17-Jun	20.8	17-Jun	
2015	11.3	30-Apr	10.6	30-Apr	
2016	29.3	24-May	26.0	24-May	
2017	34.2	10-Jun	27.5	11-Jun	
2018	27.8	05-Jul	24.4	04-Jul	
2019	108.0	08-Jul	96.2	08-Jul	
2020	123.0	02-Jul	107.0	02-Jul	
2021	20.5	02-Sep	16.9	02-Sep	
2022	22.5	03-Jul	19.7	03-Jul	
2023	**211.2**		179.0	20-Jun	
2024	18.4	23-May	17.6	23-May	

07AF014 – Embarras River near Weald



Notes: 1. The bolded and underlined values are based on Qi=1.18Qd.
2. Data for 2024 is preliminary from WSC.

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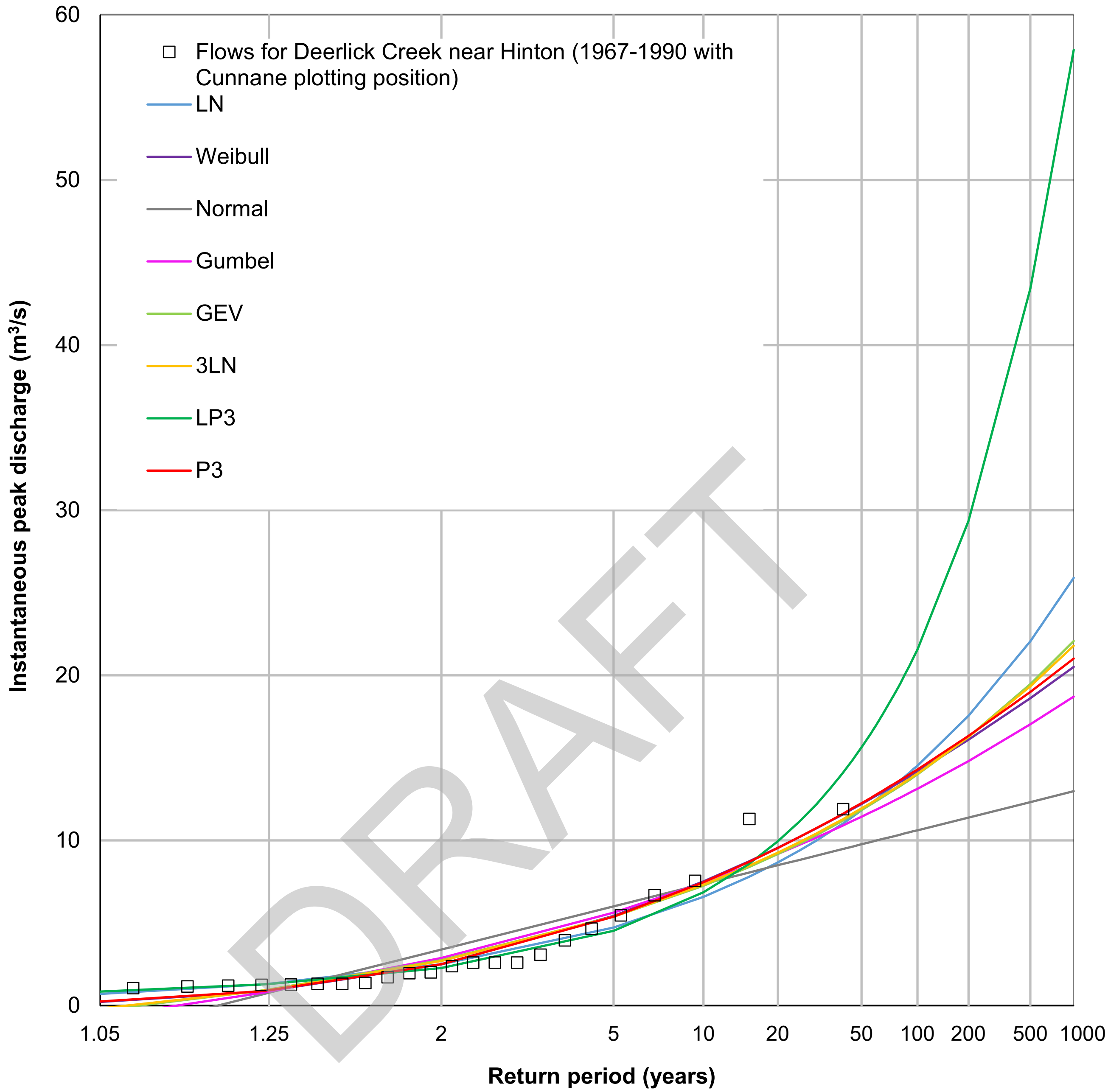
Job: 1009252 *Date: 03-OCT-2024*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
EMBARRAS RIVER NEAR WEALD
MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-6

Appendix B

Flood Frequency Analysis for Regional Stations



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

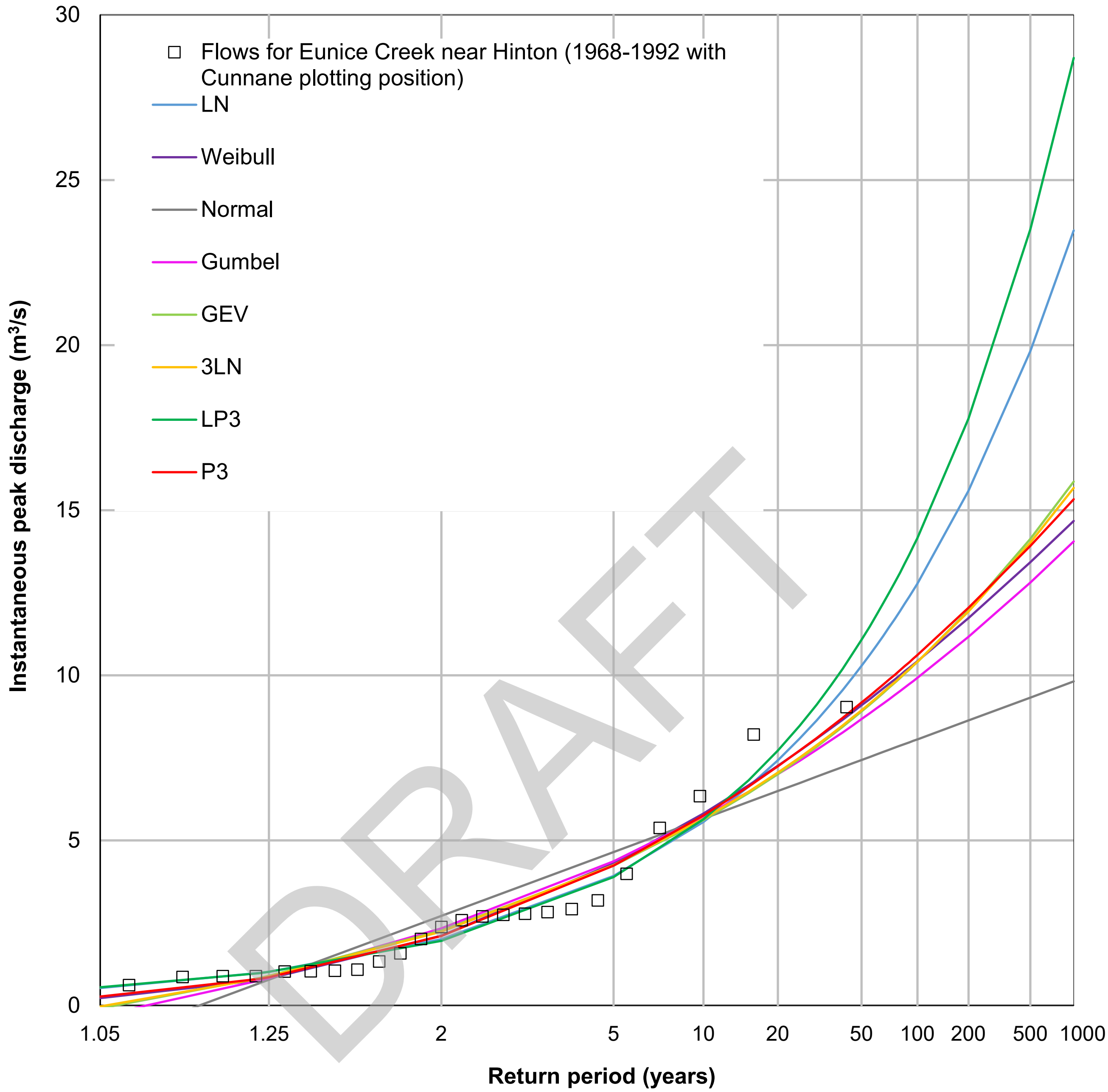
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVES FOR DEERLICK CREEK NEAR HINTON

Job: 1009252

Date: 25-OCT-2024

FIGURE B-1



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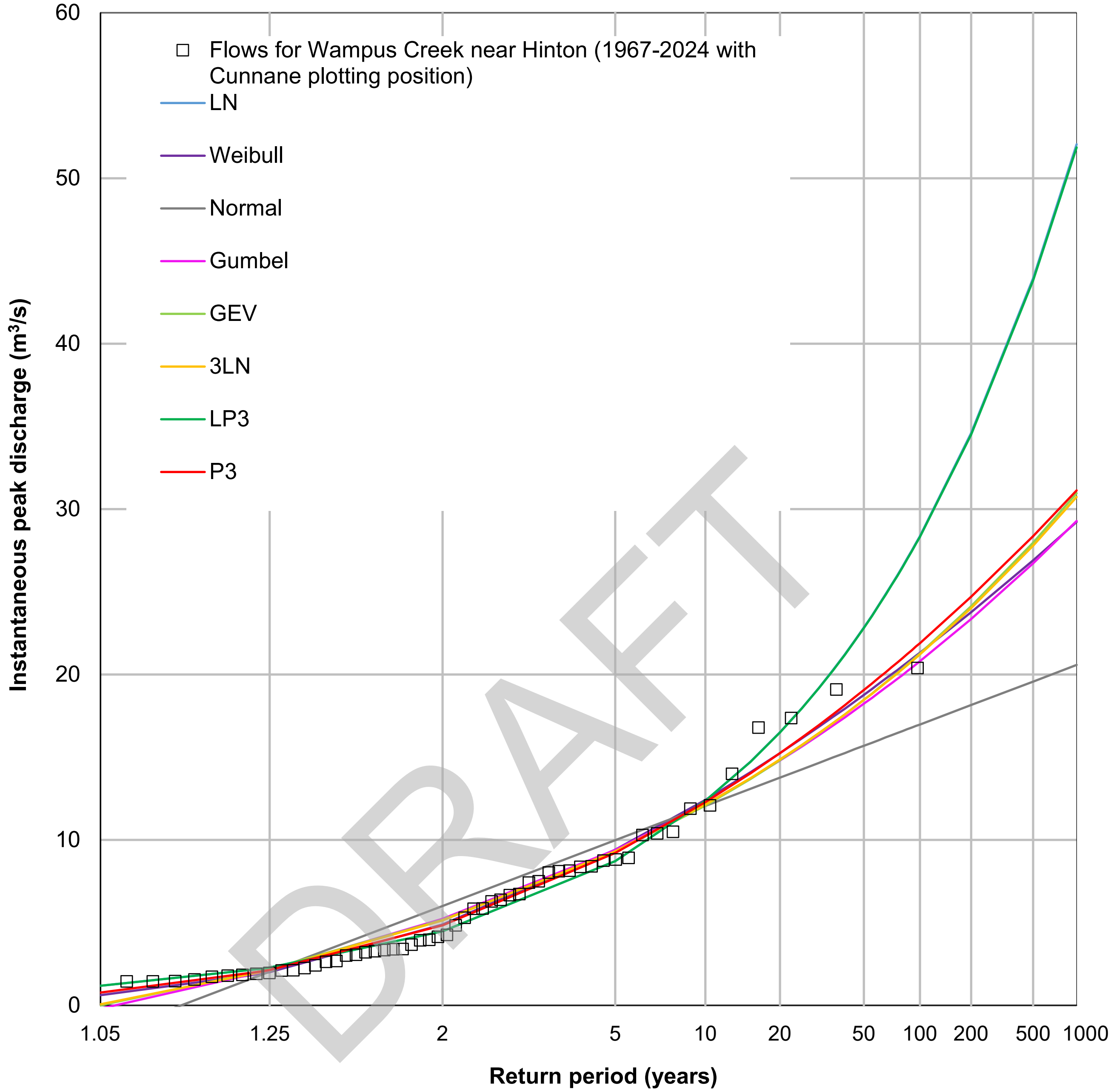
Job: 1009252 | *Date: 25-OCT-2024*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVES FOR EUNICE CREEK NEAR HINTON

FIGURE B-2



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SCALE – AS SHOWN

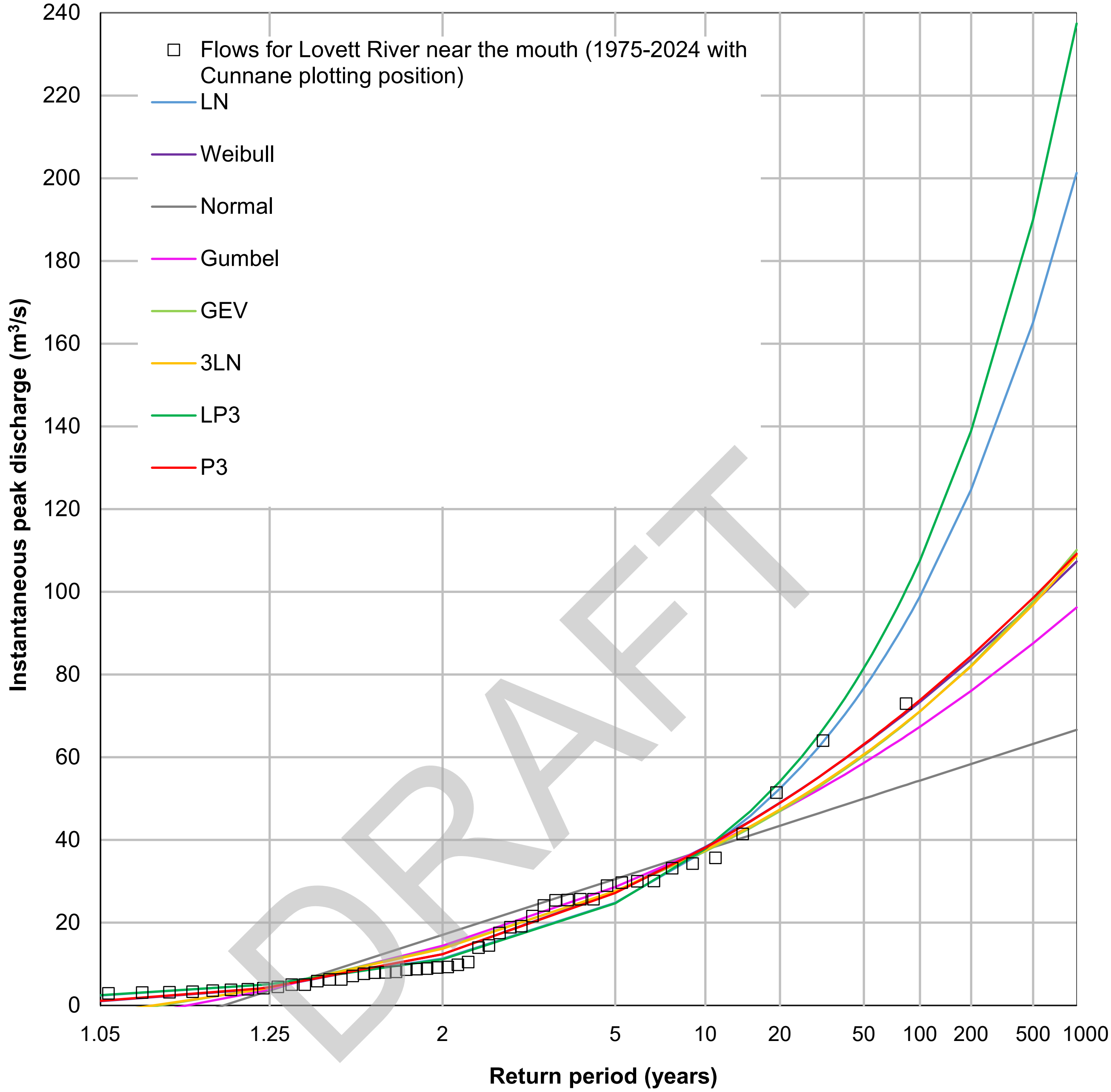
Coordinate System:
Units: As Shown

Job: 1009252 | *Date: 25-OCT-2024*

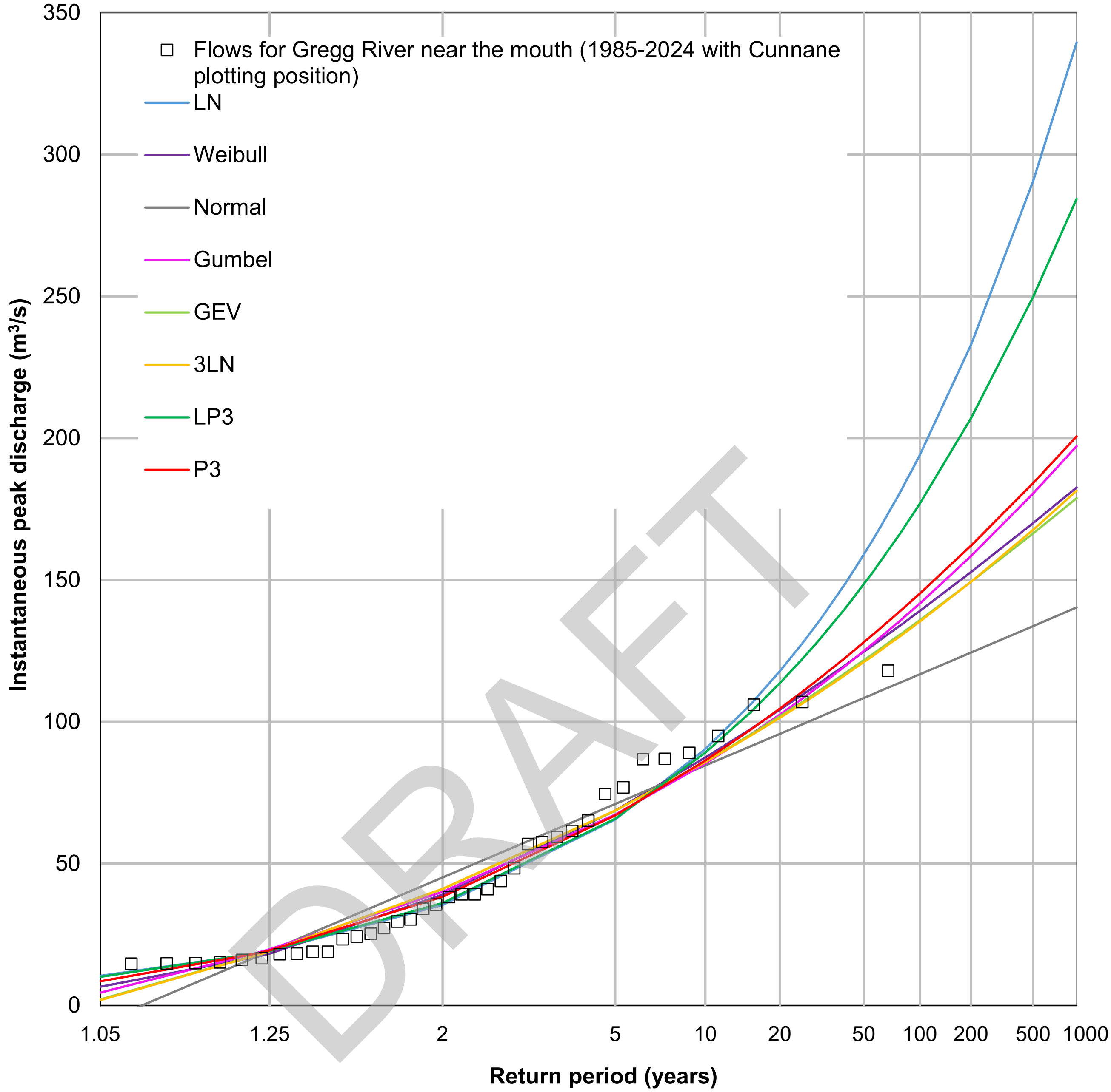
ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVES FOR WAMPUS CREEK NEAR HINTON

FIGURE B-3



Alberta Canada	SCALE – AS SHOWN	ROBB FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
nhc	Coordinate System: Units: As Shown	**FLOOD FREQUENCY CURVES FOR LOVETT RIVER NEAR THE MOUTH**
	Job: 1009252 / *Date: 25-OCT-2024*	FIGURE B-4



SCALE – AS SHOWN

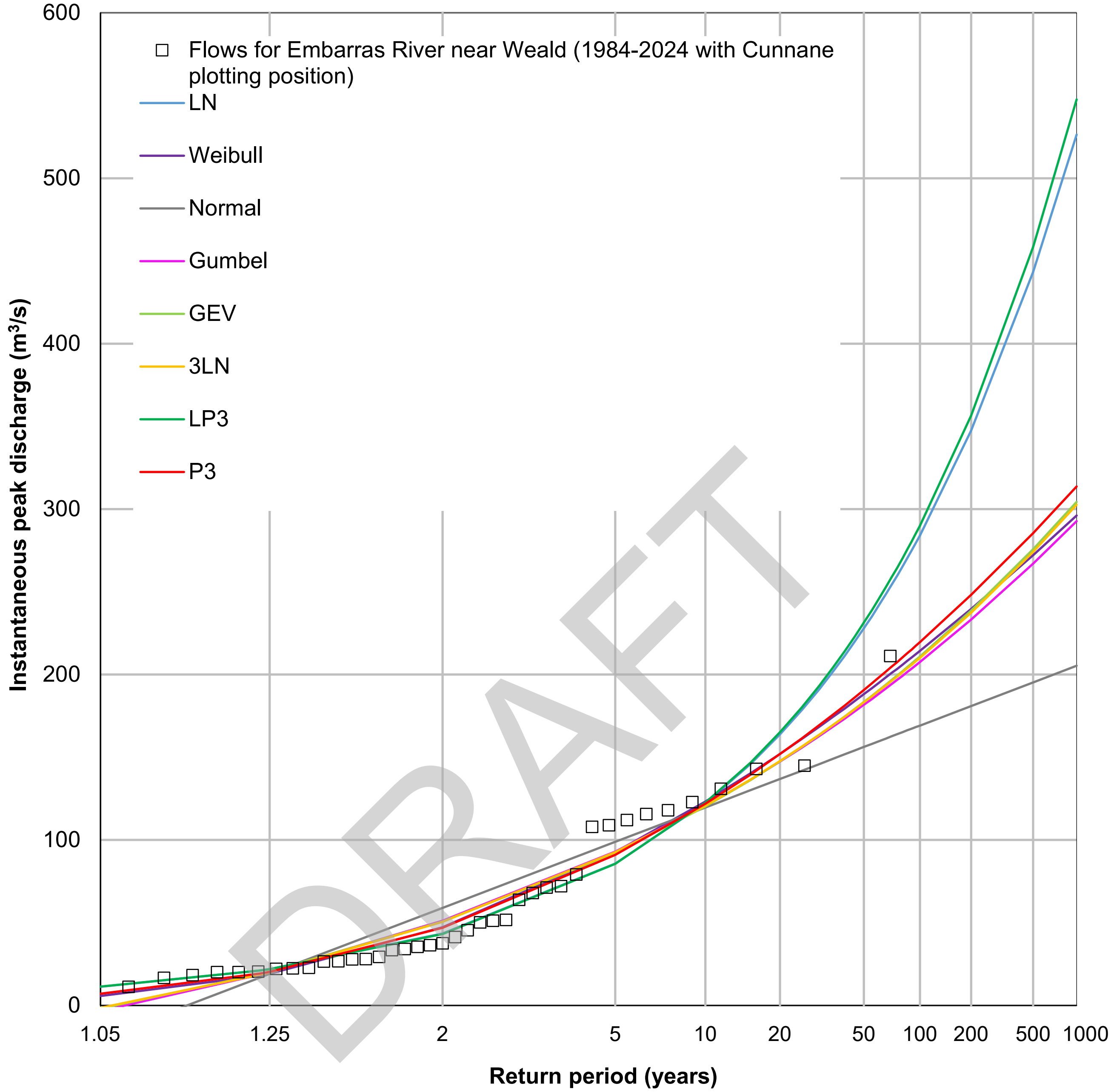
Coordinate System:
Units: As Shown

Job: 1009252 | *Date: 25-OCT-2024*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVES FOR GREGG RIVER NEAR THE MOUTH

FIGURE B-5



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD FREQUENCY CURVES FOR EMBARRAS RIVER NEAR WEALD

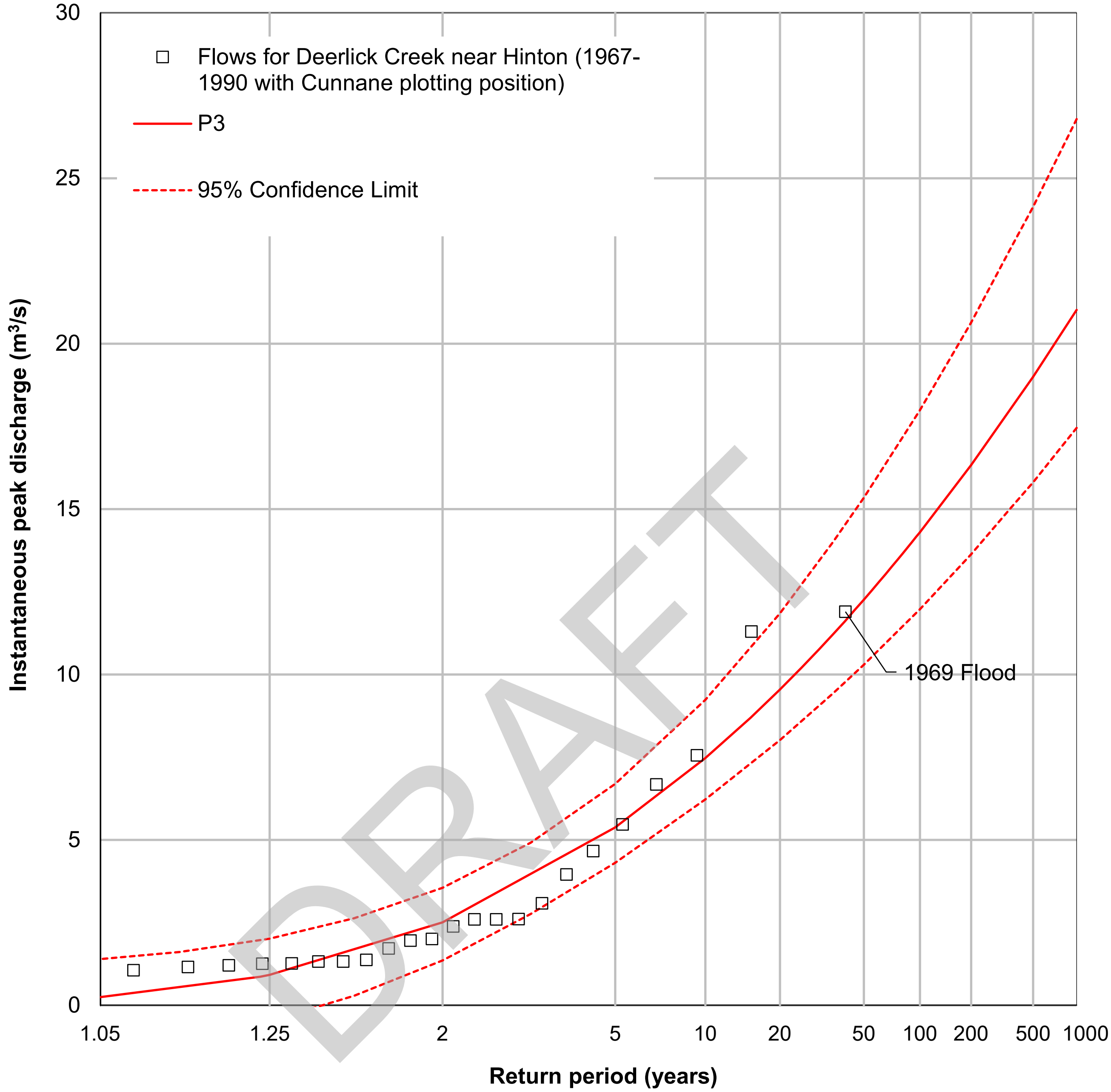
Job: 1009252 | *Date: 25-OCT-2024*

FIGURE B-6

Appendix C

Pearson Type III (P3) Flood Frequency Curve for Regional Stations

DRAFT



SCALE – AS SHOWN

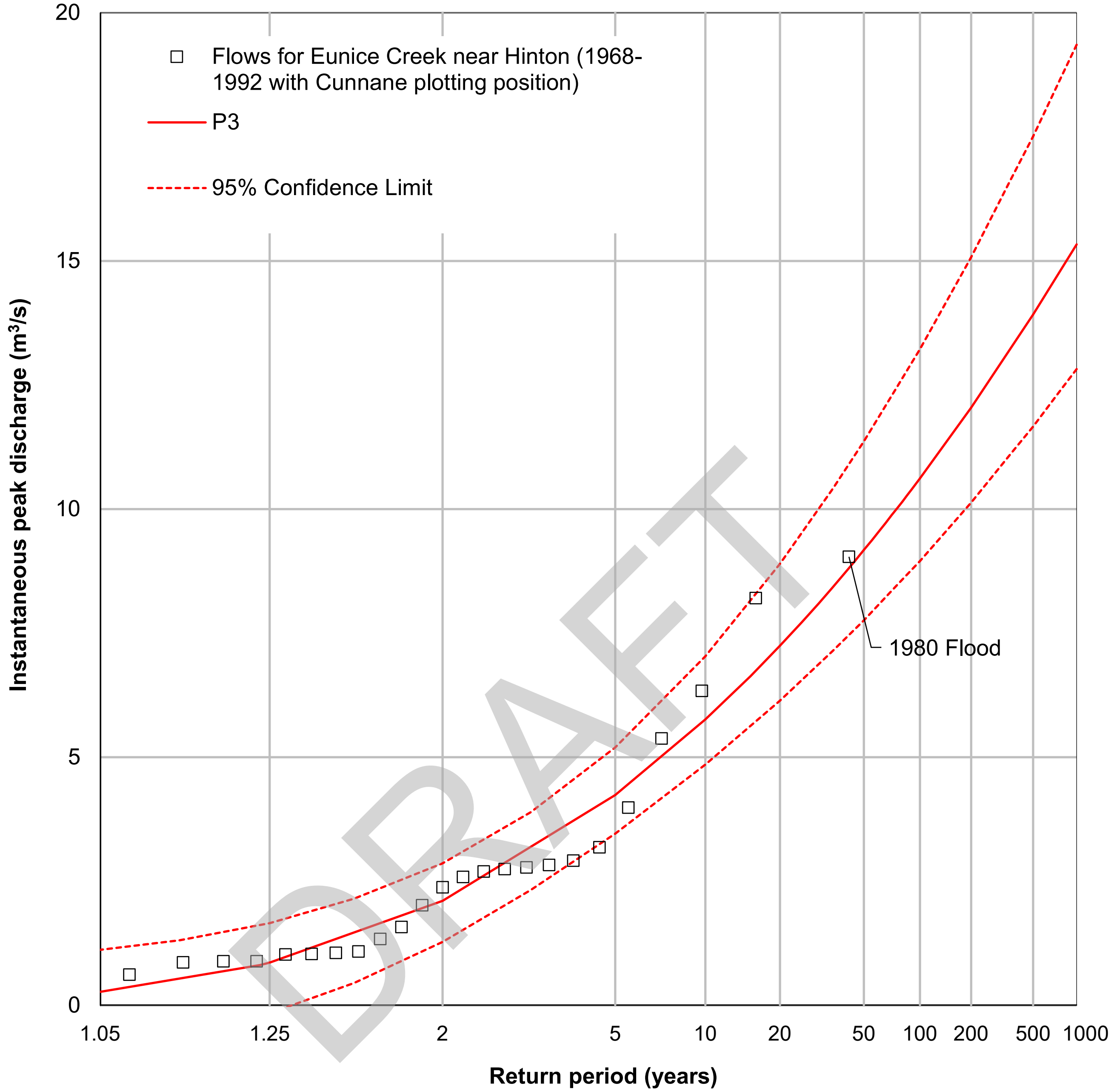
Coordinate System:
Units: As Shown

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PEARSON TYPE III (P3) FLOOD FREQUENCY CURVES FOR DEERLICK CREEK NEAR HINTON

Job: 1009252 | *Date: 27-FEB-2025*

FIGURE C-1



SCALE – AS SHOWN

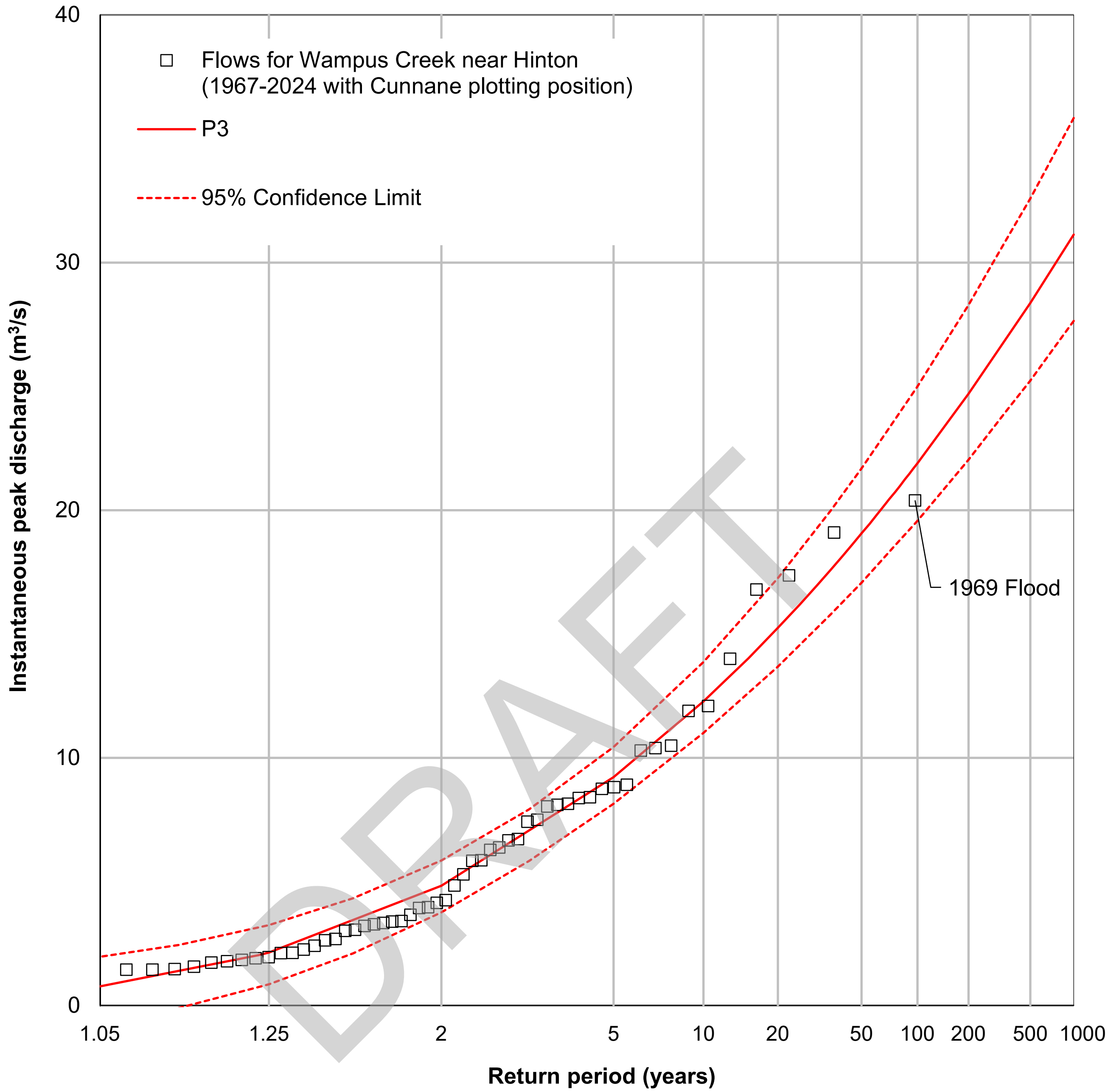
Coordinate System:
Units: As Shown

Job: 1009252 | *Date: 27-FEB-2025*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PEARSON TYPE III (P3) FLOOD FREQUENCY CURVES FOR EUNICE CREEK NEAR HINTON

FIGURE C-2



SCALE – AS SHOWN

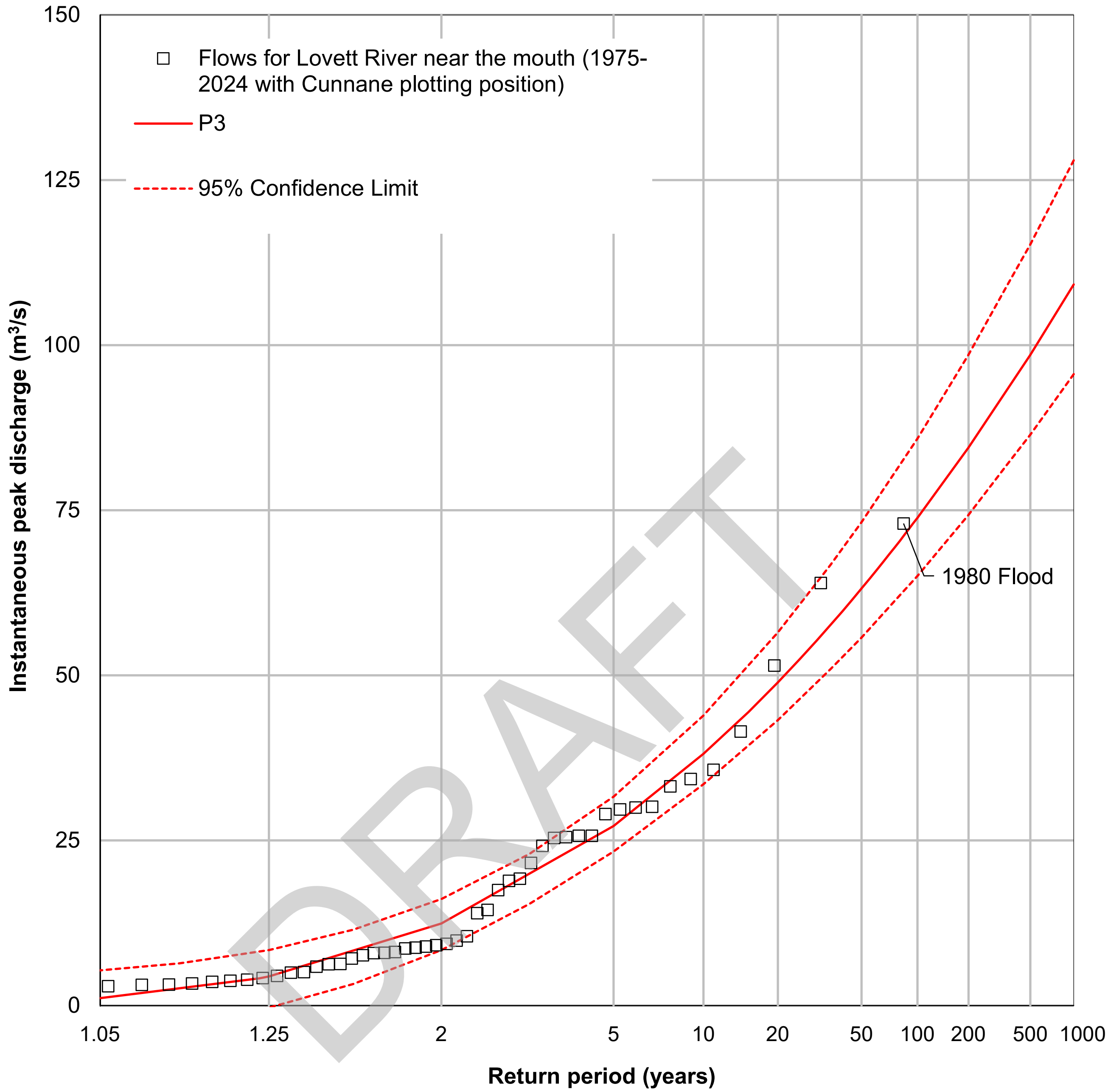
Coordinate System:
Units: As Shown

Job: 1009252 | *Date: 27-FEB-2025*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PEARSON TYPE III (P3) FLOOD FREQUENCY CURVES FOR WAMPUS CREEK NEAR HINTON

FIGURE C-3



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Coordinate System:
Units: As Shown

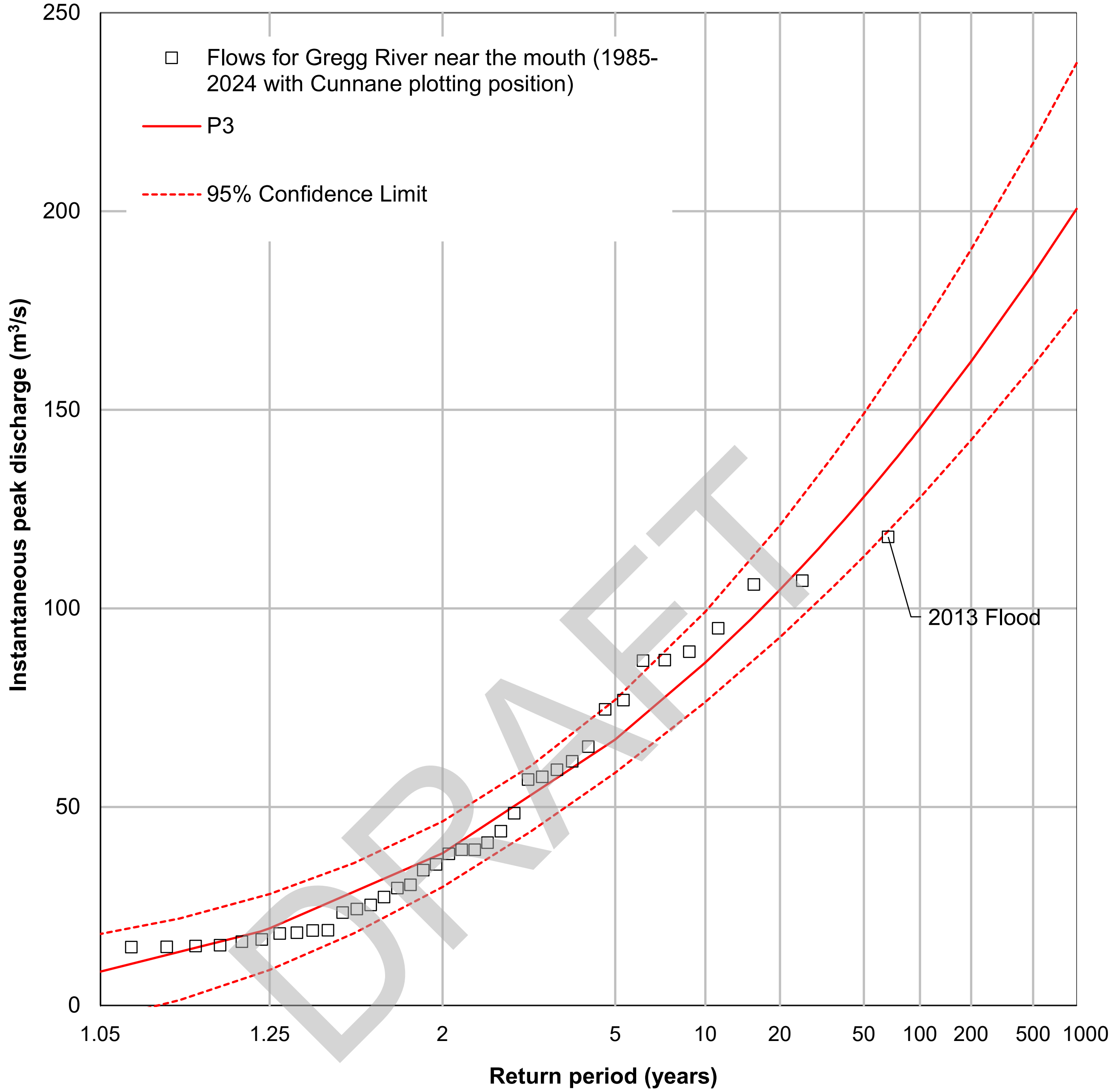
Job: 1009252

Date: 27-FEB-2025

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PEARSON TYPE III (P3) FLOOD FREQUENCY CURVES FOR LOVETT RIVER NEAR THE MOUTH

FIGURE C-4



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Units: As Shown

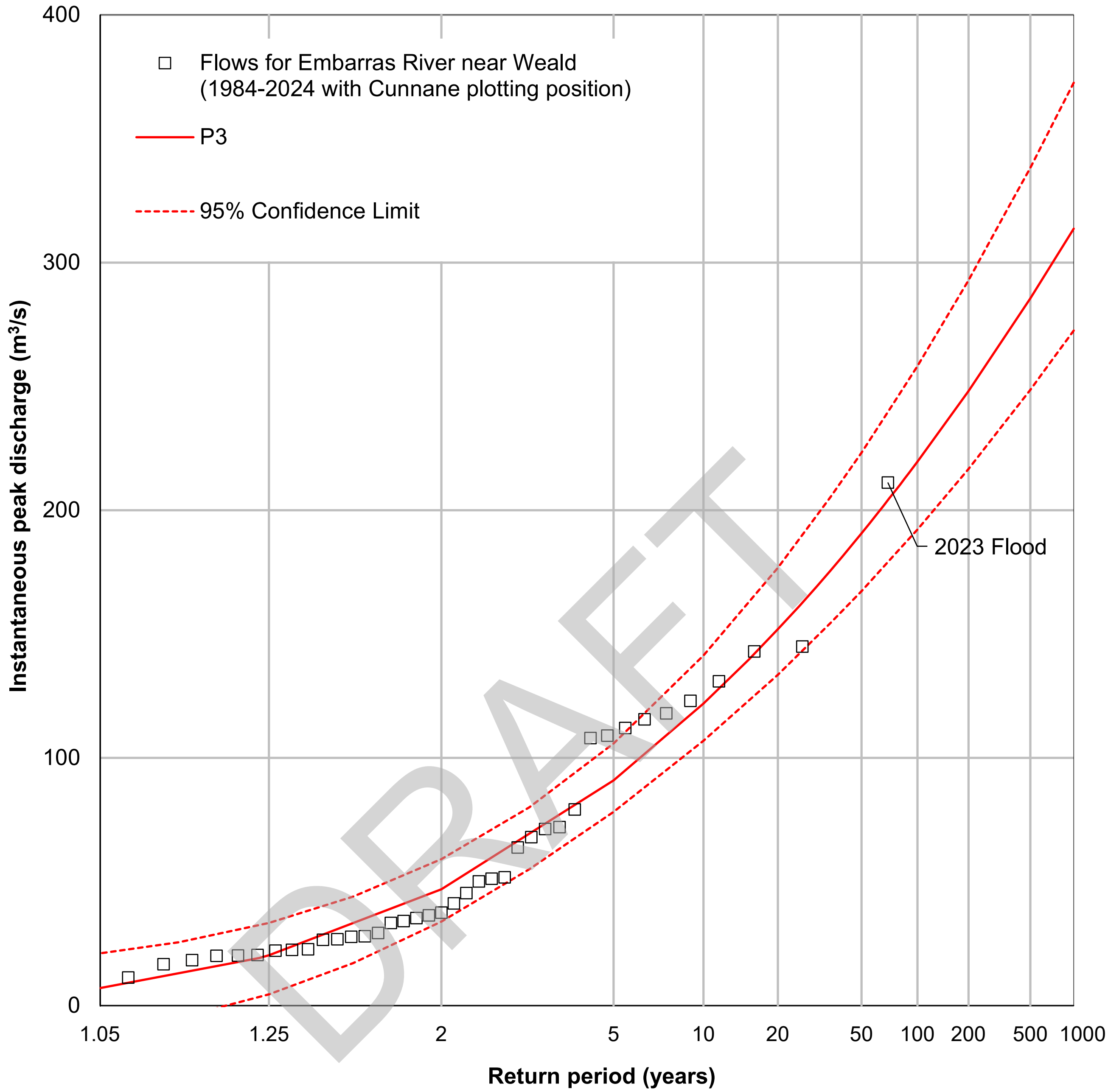
Job: 1009252

Date: 27-FEB-2025

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PEARSON TYPE III (P3) FLOOD FREQUENCY CURVES FOR GREGG RIVER NEAR THE MOUTH

FIGURE C-5



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

Job: 1009252 | *Date: 27-FEB-2025*

ROBB FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

PEARSON TYPE III (P3) FLOOD FREQUENCY CURVES FOR EMBARRAS RIVER NEAR WEALD

FIGURE C-6

September 2025

APPENDIX E

DETAILED MODEL DATA

Robb Flood Study
Main Report

Table E-1 Cross section properties for Embarras River

River	Cross Section Number	River Station (m)	Thalweg Elevation (m)	2-year Water Surface Width (m)	River	Cross Section Number	River Station (m)	Thalweg Elevation (m)	2-year Water Surface Width (m)
Embarras River	XS-83	10796	1131.39	7.54	Embarras River	XS-53	6867	1102.41	16.94
	XS-82	10649	1129.73	13.61		XS-52	6856	1102.43	17.92
	XS-81	10474	1130.06	16.73		XS-51	6832	1102.40	14.03
	XS-80	10389	1129.20	30.53		XS-50	6738	1101.40	13.94
	XS-79	10178	1128.64	68.87		XS-49	6609	1100.48	11.79
	XS-78	9974	1128.07	12.93		XS-48	6557	1100.21	12.57
	XS-77	9887	1126.51	15.55		XS-47	6541	1100.31	14.21
	XS-76	9877	1127.03	12.79		XS-46	6487	1099.88	14.52
	XS-75	9834	1127.26	13.93		XS-45	6358	1098.47	11.58
	XS-74	9689	1125.23	18.82		XS-44	6225	1098.40	15.27
	XS-73	9500	1125.86	37.32		XS-43	6086	1097.73	15.31
	XS-72	9271	1124.18	10.69		XS-42	5928	1096.17	15.11
	XS-71	9113	1123.26	28.72		XS-41	5777	1095.70	18.77
	XS-70	9021	1123.34	21.56		XS-40	5647	1094.33	14.52
	XS-69	9005	1123.23	20.62		XS-39	5463	1093.09	18.10
	XS-68	8959	1122.45	20.61		XS-38	5331	1091.33	14.68
	XS-67	8864	1122.15	73.33		XS-37	5182	1090.16	17.47
	XS-66	8721	1122.75	32.96		XS-36	5058	1089.19	13.15
	XS-65	8669	1121.81	35.10		XS-35	4968	1087.74	36.12
	XS-64	8593	1120.48	25.22		XS-34	4890	1088.12	15.14
	XS-63	8350	1119.47	16.57		XS-33	4778	1087.59	48.82
	XS-62	8204	1117.93	15.98		XS-32	4663	1087.02	115.09
	XS-61	8007	1116.48	16.58		XS-31	4579	1086.26	72.38
	XS-60	7809	1112.72	14.57		XS-30	4515	1083.19	33.32
	XS-59	7639	1110.07	9.31		XS-29	4496	1084.64	17.03
	XS-58	7404	1107.24	12.82		XS-28	4383	1083.28	27.36
	XS-57	7254	1105.62	15.33		XS-27	4293	1083.29	15.05
	XS-56	7143	1104.67	13.58		XS-26	3939	1081.05	20.32
	XS-55	7036	1104.41	17.38		XS-25	3687	1079.65	12.29
	XS-54	6926	1102.41	12.74		XS-24	3554	1078.16	47.07

Table E-1 Cross section properties for Embarras River (Continued)

River	Cross Section Number	River Station (m)	Thalweg Elevation (m)	2-year Water Surface Width (m)	River	Cross Section Number	River Station (m)	Thalweg Elevation (m)	2-year Water Surface Width (m)
Embarras River	XS-23	3422	1078.00	18.46	Embarras River	XS-11	1783	1071.21	15.80
	XS-22	3284	1077.29	14.23		XS-10	1610	1070.59	60.83
	XS-21	3265	1077.03	15.99		XS-9	1463	1070.22	20.40
	XS-20	3194	1076.79	13.30		XS-8	1347	1069.80	15.26
	XS-19	3044	1075.84	16.47		XS-7	1226	1069.49	28.22
	XS-18	2935	1075.37	17.28		XS-6	1054	1068.18	16.99
	XS-17	2765	1075.24	29.74		XS-5	898	1067.75	19.48
	XS-16	2597	1074.66	15.74		XS-4	617	1066.60	16.41
	XS-15	2415	1073.79	16.99		XS-3	390	1065.71	18.26
	XS-14	2252	1072.80	17.68		XS-2	224	1064.51	20.94
	XS-13	2100	1072.24	14.49		XS-1	0	1063.60	16.89
	XS-12	1917	1071.87	21.35					

Table E-2 Cross section properties for Bryan Creek

River	Cross Section Number	River Station (m)	Thalweg Elevation (m)	2-year Water Surface Width (m)	River	Cross Section Number	River Station (m)	Thalweg Elevation (m)	2-year Water Surface Width (m)
Bryan Creek	XS-111	3352	1120.56	10.52	Bryan Creek	XS-97	1319	1106.11	5.74
	XS-110	3222	1120.15	5.14		XS-96	1084	1102.95	6.47
	XS-109	3162	1119.90	3.74		XS-95	968	1102.31	4.46
	XS-108	3044	1118.70	5.98		XS-94	844	1101.20	7.58
	XS-107	2870	1118.02	4.14		XS-93	740	1099.89	5.30
	XS-106	2707	1116.69	5.35		XS-92	611	1098.93	32.47
	XS-105	2510	1115.94	4.08		XS-91	553	1098.18	14.67
	XS-104	2329	1115.08	7.13		XS-90	510	1096.85	8.09
	XS-103	2198	1114.31	5.01		XS-89	408	1095.67	6.17
	XS-102	2013	1112.73	7.94		XS-88	301	1093.98	5.36
	XS-101	1811	1110.79	4.79		XS-87	245	1092.96	6.74
	XS-100	1653	1109.50	5.61		XS-86	153	1091.43	5.47
	XS-99	1470	1108.81	13.82		XS-85	95	1090.74	6.62
	XS-98	1387	1108.18	11.33		XS-84	8	1088.55	29.95

Table E-3 Modelled bridge properties

River	Description	River Station (m)	Location	TEC Bridge File	Design Drawing/ Info	Span (m)	Width (m)	Number of Piers	Pier Width (m)	Deck Skew (°)	Minimum Elevation (m)		Low Flow Modelling Approach	High Flow Modelling Approach
											Top Chord	Low Chord		
Embarras River	CN Railway	9882	Upstream of Mile 34	BF496	No	21.9	4.7	0	N/A	N/A	1132.71	1130.61	Energy (Standard Step)	Energy only (Standard step)
Embarras River	Private Crossing	9017	Mile 34	N/A	No	31.7	2.3	1	0.2	N/A	1126.28	1125.83	Highest Energy Answer	Energy only (Standard step)
Embarras River	Embarras Drive (South)	6862	Lower Robb	BF 70587	No	19.4	6.4	0	N/A	N/A	1106.12	1105.73	Energy (Standard Step)	Energy only (Standard step)
Embarras River	Embarras Drive (North)	6543	Lower Robb	BF 76138	No	19.2	6.1	0	N/A	N/A	1104.69	1104.36	Energy (Standard Step)	Energy only (Standard step)
Embarras River	Old Railway	3274	Downstream of Upper Robb	N/A	No	114.9	6.5	2	2.0	N/A	1096.85	1093.84	Highest Energy Answer	Energy only (Standard step)

Table E-4 Modelled culvert properties

River	Description	River Station (m)	Location	TEC Bridge File	Design Drawing/ Info	Culvert Shape	Culvert Type	Entrance Condition	# Barrels	Barrel Length (m)	Diameter, Rise, or Height (m)	Span or Width (m)	Upstream Invert Elevation (m)	Downstream Invert Elevation (m)	Loss Coefficient		Mannings's n	
															Entrance	Exit	Top	Bottom
Embarras River	Township Road 492A	4541	Upper Robb	N/A	No	Circular	CSP	Pipe Projecting from Fill	1	54.9	4.5	N/A	1087.07	1085.86	0.9	1	0.024	0.024
Bryan Creek	Highway 47	1352	Upper Robb	BF 70904	No	Circular	CSP	Pipe Projecting from Fill	1	64.1	3.3	N/A	1108.54	1106.78	0.9	1	0.024	0.024
Bryan Creek	Valley Road	528	Upper Robb	BF 73286	No	Circular	CSP	Pipe Projecting from Fill	1	39.4	3	N/A	1098.77	1097.49	0.9	1	0.024	0.024
Bryan Creek	CN Railway	49	Upper Robb	N/A	No	Rectangular (Open Bottom)	Concrete	Side tapered; More favorable edges	1	82.0	2.24	2.45	1090.80	1088.80	0.5	1	0.013	0.06

Table E-5 Embarras River flood frequency water surface elevation

Cross Section Number	River Station (m)	Flood Return Period												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		Water Surface Elevation (m)												
XS-83	10,796	1132.54	1133.21	1133.54	1133.74	1133.86	1133.93	1134.00	1134.05	1134.16	1134.25	1134.30	1134.35	1134.39
XS-82	10,649	1131.97	1132.63	1132.88	1133.07	1133.20	1133.27	1133.34	1133.38	1133.49	1133.57	1133.61	1133.66	1133.69
XS-81	10,474	1131.40	1132.00	1132.24	1132.39	1132.49	1132.55	1132.60	1132.64	1132.73	1132.80	1132.83	1132.87	1132.89
XS-80	10,389	1131.18	1131.69	1131.90	1132.02	1132.10	1132.14	1132.18	1132.21	1132.28	1132.34	1132.37	1132.40	1132.42
XS-79	10,178	1130.70	1131.00	1131.15	1131.27	1131.36	1131.41	1131.46	1131.49	1131.56	1131.61	1131.64	1131.67	1131.69
XS-78	9,974	1128.88	1129.51	1129.81	1130.04	1130.21	1130.31	1130.42	1130.49	1130.65	1130.77	1130.85	1130.93	1130.99
XS-77	9,887	1128.65	1129.18	1129.49	1129.73	1129.89	1129.99	1130.09	1130.16	1130.30	1130.41	1130.47	1130.54	1130.59
XS-76	9,877	1128.60	1129.10	1129.39	1129.62	1129.77	1129.86	1129.96	1130.02	1130.14	1130.24	1130.29	1130.34	1130.38
XS-75	9,834	1128.22	1128.74	1129.01	1129.23	1129.38	1129.46	1129.55	1129.61	1129.75	1129.85	1129.90	1129.97	1130.02
XS-74	9,689	1127.66	1128.14	1128.35	1128.51	1128.63	1128.69	1128.76	1128.81	1128.91	1128.98	1129.03	1129.08	1129.11
XS-73	9,500	1127.09	1127.55	1127.74	1127.90	1128.01	1128.06	1128.13	1128.17	1128.25	1128.31	1128.35	1128.39	1128.42
XS-72	9,271	1125.36	1125.80	1126.04	1126.26	1126.40	1126.49	1126.59	1126.65	1126.79	1126.90	1126.95	1127.02	1127.05
XS-71	9,113	1124.80	1125.22	1125.46	1125.67	1125.81	1125.90	1125.99	1126.06	1126.20	1126.30	1126.37	1126.43	1126.46
XS-70	9,021	1124.49	1124.90	1125.10	1125.28	1125.40	1125.48	1125.56	1125.62	1125.76	1125.86	1125.94	1126.01	1126.05
XS-69	9,005	1124.35	1124.76	1124.96	1125.13	1125.26	1125.33	1125.41	1125.47	1125.59	1125.68	1125.73	1125.78	1125.82
XS-68	8,959	1124.16	1124.53	1124.72	1124.89	1125.01	1125.08	1125.16	1125.21	1125.33	1125.41	1125.46	1125.51	1125.54
XS-67	8,864	1123.98	1124.31	1124.50	1124.66	1124.78	1124.84	1124.92	1124.97	1125.08	1125.16	1125.20	1125.26	1125.29
XS-66	8,721	1123.53	1123.80	1123.90	1123.98	1124.04	1124.07	1124.11	1124.14	1124.21	1124.28	1124.31	1124.36	1124.39
XS-65	8,669	1122.64	1122.98	1123.16	1123.32	1123.44	1123.52	1123.59	1123.65	1123.77	1123.87	1123.92	1123.98	1124.02
XS-64	8,593	1121.99	1122.36	1122.60	1122.80	1122.94	1123.03	1123.11	1123.17	1123.31	1123.41	1123.46	1123.52	1123.56
XS-63	8,350	1120.39	1120.81	1121.08	1121.29	1121.42	1121.50	1121.57	1121.62	1121.74	1121.83	1121.88	1121.94	1121.98
XS-62	8,204	1119.33	1119.79	1120.04	1120.25	1120.39	1120.47	1120.55	1120.61	1120.73	1120.83	1120.88	1120.95	1120.99
XS-61	8,007	1117.27	1117.55	1117.71	1117.85	1117.94	1117.99	1118.06	1118.10	1118.20	1118.27	1118.31	1118.35	1118.38
XS-60	7,809	1113.79	1114.22	1114.47	1114.70	1114.84	1114.93	1115.03	1115.09	1115.25	1115.37	1115.44	1115.52	1115.58

Table E-5 Embarras River flood frequency water surface elevation (Continued)

Cross Section Number	River Station (m)	Flood Return Period												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		Water Surface Elevation (m)												
XS-59	7,639	1111.36	1111.92	1112.17	1112.37	1112.50	1112.57	1112.64	1112.69	1112.79	1112.87	1112.92	1112.96	1113.00
XS-58	7,404	1108.14	1108.56	1108.84	1109.04	1109.18	1109.26	1109.35	1109.41	1109.55	1109.65	1109.70	1109.77	1109.81
XS-57	7,254	1106.75	1107.26	1107.54	1107.78	1107.94	1108.03	1108.14	1108.19	1108.30	1108.37	1108.40	1108.45	1108.48
XS-56	7,143	1106.12	1106.58	1106.82	1107.01	1107.15	1107.21	1107.29	1107.32	1107.39	1107.45	1107.48	1107.51	1107.53
XS-55	7,036	1105.27	1105.70	1105.97	1106.16	1106.27	1106.34	1106.41	1106.45	1106.55	1106.60	1106.64	1106.68	1106.72
XS-54	6,926	1104.10	1104.55	1104.84	1105.07	1105.26	1105.34	1105.44	1105.51	1105.66	1105.79	1105.86	1105.93	1105.98
XS-53	6,867	1103.72	1104.15	1104.41	1104.63	1104.79	1104.89	1105.00	1105.07	1105.22	1105.36	1105.42	1105.49	1105.53
XS-52	6,856	1103.59	1104.01	1104.27	1104.49	1104.64	1104.73	1104.83	1104.90	1105.04	1105.18	1105.23	1105.28	1105.30
XS-51	6,832	1103.30	1103.76	1104.04	1104.26	1104.42	1104.52	1104.62	1104.69	1104.84	1104.95	1105.01	1105.06	1105.09
XS-50	6,738	1102.53	1103.11	1103.42	1103.65	1103.80	1103.88	1103.97	1104.02	1104.15	1104.25	1104.30	1104.37	1104.42
XS-49	6,609	1101.84	1102.42	1102.70	1102.93	1103.10	1103.20	1103.31	1103.38	1103.56	1103.69	1103.77	1103.86	1103.92
XS-48	6,557	1101.57	1102.11	1102.41	1102.64	1102.80	1102.89	1102.99	1103.05	1103.20	1103.32	1103.39	1103.47	1103.52
XS-47	6,541	1101.48	1102.01	1102.30	1102.53	1102.69	1102.77	1102.87	1102.93	1103.08	1103.19	1103.26	1103.33	1103.38
XS-46	6,487	1101.18	1101.72	1102.00	1102.24	1102.40	1102.48	1102.58	1102.64	1102.79	1102.89	1102.96	1103.03	1103.08
XS-45	6,358	1100.28	1100.82	1101.11	1101.33	1101.48	1101.57	1101.66	1101.72	1101.86	1101.96	1102.03	1102.10	1102.15
XS-44	6,225	1099.54	1100.02	1100.30	1100.51	1100.66	1100.75	1100.84	1100.90	1101.05	1101.16	1101.22	1101.30	1101.35
XS-43	6,086	1098.62	1099.12	1099.39	1099.59	1099.72	1099.80	1099.88	1099.93	1100.04	1100.14	1100.18	1100.24	1100.27
XS-42	5,928	1097.70	1098.14	1098.36	1098.53	1098.64	1098.69	1098.75	1098.79	1098.89	1098.95	1099.01	1099.07	1099.12
XS-41	5,777	1096.70	1097.10	1097.32	1097.50	1097.63	1097.71	1097.81	1097.87	1097.97	1098.42	1098.52	1098.60	1098.66
XS-40	5,647	1095.54	1095.98	1096.23	1096.46	1096.62	1096.69	1096.69	1096.69*	1097.38	1098.20	1098.31	1098.39	1098.45
XS-39	5,463	1093.92	1094.25	1094.46	1094.57	1094.66	1094.77	1095.11	1095.56	1097.14	1098.09	1098.20	1098.28	1098.34
XS-38	5,331	1092.25	1092.69	1092.92	1093.33	1093.81	1094.16	1094.80	1095.39	1097.09	1098.07	1098.18	1098.26	1098.31
XS-37	5,182	1091.21	1091.68	1092.29	1093.00	1093.61	1094.02	1094.73	1095.35	1097.08	1098.06	1098.17	1098.25	1098.30
XS-36	5,058	1090.05	1091.29	1092.11	1092.91	1093.57	1093.99	1094.71	1095.34	1097.08	1098.06	1098.17	1098.24	1098.29

Table E-5 Embarras River flood frequency water surface elevation (Continued)

Cross Section Number	River Station (m)	Flood Return Period												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		Water Surface Elevation (m)												
XS-35	4,968	1090.05	1091.29	1092.11	1092.91	1093.57	1093.99	1094.71	1095.34	1097.08	1098.06	1098.17	1098.24	1098.29
XS-34	4,890	1089.96	1091.23	1092.06	1092.87	1093.53	1093.95	1094.68	1095.30	1097.05	1098.04	1098.14	1098.22	1098.27
XS-33	4,778	1089.82	1091.14	1091.98	1092.80	1093.47	1093.89	1094.64	1095.27	1097.03	1098.02	1098.12	1098.20	1098.25
XS-32	4,663	1089.76	1091.09	1091.94	1092.77	1093.44	1093.86	1094.61	1095.25	1097.02	1098.01	1098.11	1098.19	1098.24
XS-31	4,579	1089.72	1091.04	1091.90	1092.72	1093.40	1093.82	1094.58	1095.22	1096.99	1097.98	1098.09	1098.16	1098.21
XS-30	4,515	1085.97	1086.40	1086.59	1086.76	1086.87	1086.94	1087.01	1087.06	1087.19	1087.29	1087.36	1087.42	1087.47
XS-29	4,496	1085.77	1086.20	1086.39	1086.57	1086.70	1086.78	1086.87	1086.93	1087.08	1087.19	1087.26	1087.33	1087.39
XS-28	4,383	1084.96	1085.50	1085.77	1086.01	1086.18	1086.28	1086.40	1086.47	1086.65	1086.78	1086.86	1086.94	1087.00
XS-27	4,293	1084.40	1084.95	1085.25	1085.48	1085.65	1085.75	1085.87	1085.94	1086.09	1086.20	1086.27	1086.35	1086.40
XS-26	3,939	1082.61	1083.13	1083.45	1083.69	1083.85	1083.95	1084.06	1084.12	1084.26	1084.36	1084.41	1084.48	1084.52
XS-25	3,687	1080.63	1081.17	1081.43	1081.63	1081.78	1081.86	1081.95	1082.02	1082.15	1082.25	1082.31	1082.37	1082.42
XS-24	3,554	1080.02	1080.58	1080.88	1081.14	1081.30	1081.39	1081.48	1081.54	1081.68	1081.80	1081.86	1081.94	1081.99
XS-23	3,422	1079.47	1080.08	1080.41	1080.68	1080.85	1080.95	1081.05	1081.12	1081.28	1081.41	1081.48	1081.56	1081.61
XS-22	3,284	1078.72	1079.42	1079.81	1080.09	1080.27	1080.36	1080.46	1080.52	1080.65	1080.75	1080.81	1080.87	1080.91
XS-21	3,265	1078.49	1079.13	1079.50	1079.78	1079.97	1080.06	1080.16	1080.22	1080.36	1080.46	1080.52	1080.58	1080.63
XS-20	3,194	1078.11	1078.73	1079.09	1079.36	1079.56	1079.65	1079.75	1079.81	1079.95	1080.06	1080.12	1080.19	1080.24
XS-19	3,044	1077.48	1078.07	1078.41	1078.66	1078.82	1078.90	1078.99	1079.04	1079.16	1079.25	1079.30	1079.36	1079.40
XS-18	2,935	1077.17	1077.69	1078.00	1078.21	1078.34	1078.41	1078.49	1078.54	1078.65	1078.74	1078.78	1078.84	1078.88
XS-17	2,765	1076.63	1077.17	1077.50	1077.71	1077.84	1077.92	1078.01	1078.06	1078.19	1078.28	1078.33	1078.41	1078.45
XS-16	2,597	1075.94	1076.52	1076.87	1077.09	1077.24	1077.32	1077.40	1077.44	1077.56	1077.64	1077.70	1077.76	1077.80
XS-15	2,415	1075.01	1075.59	1075.94	1076.20	1076.38	1076.49	1076.60	1076.67	1076.83	1076.96	1077.03	1077.11	1077.16
XS-14	2,252	1074.24	1074.92	1075.26	1075.54	1075.73	1075.84	1075.96	1076.04	1076.21	1076.33	1076.39	1076.46	1076.50
XS-13	2,100	1073.77	1074.40	1074.72	1074.98	1075.17	1075.27	1075.39	1075.46	1075.62	1075.73	1075.78	1075.85	1075.89
XS-12	1,917	1073.21	1073.82	1074.12	1074.37	1074.53	1074.63	1074.73	1074.79	1074.94	1075.03	1075.07	1075.14	1075.18

Table E-5 Embarras River flood frequency water surface elevation (Continued)

Cross Section Number	River Station (m)	Flood Return Period												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		Water Surface Elevation (m)												
XS-11	1,783	1072.75	1073.35	1073.61	1073.80	1073.93	1074.01	1074.09	1074.14	1074.34	1074.41	1074.45	1074.50	1074.53
XS-10	1,610	1072.20	1072.73	1073.02	1073.26	1073.41	1073.49	1073.58	1073.64	1073.79	1073.88	1073.93	1073.99	1074.03
XS-9	1,463	1071.61	1072.16	1072.50	1072.75	1072.90	1072.98	1073.07	1073.12	1073.25	1073.34	1073.39	1073.45	1073.48
XS-8	1,347	1071.06	1071.56	1071.87	1072.11	1072.26	1072.34	1072.43	1072.50	1072.64	1072.75	1072.81	1072.88	1072.92
XS-7	1,226	1070.57	1071.15	1071.46	1071.71	1071.87	1071.96	1072.06	1072.13	1072.28	1072.41	1072.47	1072.54	1072.58
XS-6	1,054	1070.00	1070.61	1070.93	1071.19	1071.36	1071.45	1071.55	1071.62	1071.75	1071.86	1071.91	1071.98	1072.02
XS-5	898	1069.42	1069.98	1070.31	1070.60	1070.80	1070.92	1071.03	1071.11	1071.27	1071.38	1071.44	1071.52	1071.56
XS-4	617	1068.13	1068.63	1068.94	1069.21	1069.39	1069.51	1069.63	1069.70	1069.87	1069.97	1070.02	1070.09	1070.13
XS-3	390	1066.79	1067.38	1067.66	1067.90	1068.06	1068.16	1068.26	1068.32	1068.48	1068.59	1068.66	1068.73	1068.78
XS-2	224	1065.96	1066.60	1066.92	1067.20	1067.39	1067.49	1067.60	1067.67	1067.84	1067.97	1068.04	1068.12	1068.17
XS-1	0	1065.06	1065.62	1065.95	1066.25	1066.45	1066.55	1066.66	1066.73	1066.89	1067.02	1067.10	1067.18	1067.24

Note: * indicates value that have been manually adjusted to eliminate the crossing profiles.

Table E-6 Bryan Creek flood frequency water surface elevation

Cross Section Number	River Station (m)	Flood Return Period												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		Water Surface Elevation (m)												
XS-111	3,352	1121.85	1122.26	1122.48	1122.66	1122.80	1122.87	1122.95	1123.00	1123.12	1123.21	1123.26	1123.31	1123.35
XS-110	3,222	1121.26	1121.74	1121.97	1122.15	1122.27	1122.33	1122.41	1122.45	1122.56	1122.64	1122.68	1122.74	1122.77
XS-109	3,162	1120.72	1121.19	1121.42	1121.59	1121.70	1121.75	1121.81	1121.85	1121.94	1122.01	1122.05	1122.10	1122.13
XS-108	3,044	1119.90	1120.41	1120.68	1120.86	1120.98	1121.05	1121.12	1121.17	1121.28	1121.36	1121.41	1121.47	1121.50
XS-107	2,870	1118.84	1119.38	1119.66	1119.85	1119.98	1120.06	1120.15	1120.20	1120.33	1120.43	1120.48	1120.54	1120.57
XS-106	2,707	1118.00	1118.60	1118.86	1119.05	1119.19	1119.26	1119.35	1119.40	1119.53	1119.62	1119.70	1119.76	1119.79
XS-105	2,510	1117.13	1117.64	1117.88	1118.03	1118.13	1118.19	1118.26	1118.30	1118.40	1118.48	1118.53	1118.57	1118.60
XS-104	2,329	1116.17	1116.57	1116.81	1116.97	1117.09	1117.15	1117.22	1117.26	1117.37	1117.44	1117.48	1117.53	1117.56
XS-103	2,198	1115.24	1115.63	1115.81	1115.95	1116.05	1116.11	1116.17	1116.21	1116.31	1116.39	1116.43	1116.48	1116.52
XS-102	2,013	1113.65	1113.93	1114.15	1114.32	1114.45	1114.52	1114.60	1114.65	1114.77	1114.86	1114.91	1114.96	1115.00
XS-101	1,811	1111.59	1112.10	1112.37	1112.56	1112.69	1112.75	1112.82	1112.87	1112.98	1113.08	1113.14	1113.22	1113.28
XS-100	1,653	1110.80	1111.27	1111.44	1111.61	1111.77	1111.88	1112.00	1112.10	1112.32	1112.52	1112.64	1112.79	1112.89
XS-99	1,470	1110.10	1110.58	1110.91	1111.21	1111.46	1111.61	1111.78	1111.89	1112.16	1112.39	1112.52	1112.68	1112.79
XS-98	1,387	1109.81	1110.43	1110.80	1111.13	1111.39	1111.54	1111.71	1111.83	1112.11	1112.34	1112.47	1112.63	1112.74
XS-97	1,319	1106.78	1107.03	1107.22	1107.38	1107.51	1107.58	1107.66	1107.71	1107.83	1107.91	1107.96	1108.03	1108.07
XS-96	1,084	1104.49	1104.91	1105.12	1105.29	1105.42	1105.48	1105.55	1105.59	1105.68	1105.75	1105.79	1105.82	1105.85
XS-95	968	1103.55	1103.90	1104.09	1104.24	1104.34	1104.38	1104.41	1104.43	1104.49	1104.52	1104.54	1104.57	1104.59
XS-94	844	1102.03	1102.39	1102.49	1102.58	1102.67	1102.73	1102.80	1102.86	1102.97	1103.53	1103.63	1103.76	1104.11
XS-93	740	1100.78	1101.09	1101.37	1101.64	1101.89	1102.04	1102.21	1102.33	1102.38	1103.37	1103.48	1103.63	1104.03
XS-92	611	1100.17	1100.78	1101.16	1101.50	1101.78	1101.95	1102.14	1102.26	1102.30	1103.35	1103.46	1103.61	1104.02
XS-91	553	1100.09	1100.74	1101.13	1101.48	1101.77	1101.93	1102.12	1102.25	1102.28	1103.34	1103.46	1103.61	1104.02
XS-90	510	1097.65	1097.96	1098.16	1098.30	1098.41	1098.55	1098.57	1098.58	1100.56	1102.28	1102.85	1103.53	1104.02
XS-89	408	1096.52	1096.83	1097.01	1097.18	1097.26	1097.26*	1097.34	1098.06	1100.53	1102.27	1102.84	1103.52	1104.01
XS-88	301	1094.67	1094.98	1095.17	1095.30	1095.46	1096.01	1097.07	1097.98	1100.52	1102.26	1102.83	1103.52	1104.01

Table E-6 Bryan Creek flood frequency water surface elevation (Continued)

Cross Section Number	River Station (m)	Flood Return Period												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		Water Surface Elevation (m)												
XS-87	245	1093.67	1093.91	1094.03	1094.21	1095.21	1095.93	1097.05	1097.97	1100.51	1102.26	1102.83	1103.52	1104.00
XS-86	153	1092.26	1092.72	1093.08	1094.09	1095.19	1095.92	1097.05	1097.97	1100.51	1102.26	1102.83	1103.52	1104.01
XS-85	95	1091.83	1092.50	1092.92	1094.05	1095.18	1095.91	1097.04	1097.96	1100.51	1102.26	1102.83	1103.51	1104.00
XS-84	8	1090.03	1091.26	1092.08	1092.88	1093.54	1093.96	1094.69	1095.31	1097.05	1098.04	1098.14	1098.22	1098.27

Note: * indicates value that have been manually adjusted to eliminate the crossing profiles.

September 2025

APPENDIX F

SENSITIVITY ANALYSIS RESULTS

Robb Flood Study
Main Report

Table F-1 Flood level sensitivity to upstream boundary conditions

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Embarras River		
XS-83	10,796	1133.94	1134.05	1134.20
XS-82	10,649	1133.28	1133.38	1133.53
XS-81	10,474	1132.56	1132.64	1132.75
XS-80	10,389	1132.14	1132.21	1132.30
XS-79	10,178	1131.42	1131.49	1131.58
XS-78	9,974	1130.33	1130.49	1130.69
XS-77	9,887	1130.01	1130.16	1130.34
XS-76	9,877	1129.88	1130.02	1130.18
XS-75	9,834	1129.47	1129.61	1129.78
XS-74	9,689	1128.70	1128.81	1128.93
XS-73	9,500	1128.07	1128.17	1128.27
XS-72	9,271	1126.51	1126.65	1126.83
XS-71	9,113	1125.91	1126.06	1126.24
XS-70	9,021	1125.49	1125.62	1125.79
XS-69	9,005	1125.35	1125.47	1125.62
XS-68	8,959	1125.09	1125.21	1125.35
XS-67	8,864	1124.86	1124.97	1125.11
XS-66	8,721	1124.08	1124.14	1124.23
XS-65	8,669	1123.53	1123.65	1123.81
XS-64	8,593	1123.04	1123.17	1123.34
XS-63	8,350	1121.51	1121.62	1121.77
XS-62	8,204	1120.48	1120.61	1120.77
XS-61	8,007	1118.00	1118.10	1118.22
XS-60	7,809	1114.95	1115.09	1115.29
XS-59	7,639	1112.58	1112.69	1112.82
XS-58	7,404	1109.27	1109.41	1109.58
XS-57	7,254	1108.05	1108.19	1108.32
XS-56	7,143	1107.23	1107.32	1107.41

Table F-1 Flood level sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Embarras River		
XS-55	7,036	1106.35	1106.45	1106.57
XS-54	6,926	1105.36	1105.51	1105.71
XS-53	6,867	1104.90	1105.07	1105.26
XS-52	6,856	1104.74	1104.90	1105.08
XS-51	6,832	1104.53	1104.69	1104.88
XS-50	6,738	1103.90	1104.02	1104.19
XS-49	6,609	1103.22	1103.38	1103.60
XS-48	6,557	1102.90	1103.05	1103.24
XS-47	6,541	1102.79	1102.93	1103.11
XS-46	6,487	1102.50	1102.64	1102.82
XS-45	6,358	1101.58	1101.72	1101.89
XS-44	6,225	1100.76	1100.90	1101.08
XS-43	6,086	1099.81	1099.93	1100.08
XS-42	5,928	1098.70	1098.79	1098.89
XS-41	5,777	1097.73	1097.87	1098.15
XS-40	5,647	1096.69*	1096.69*	1097.82
XS-39	5,463	1094.79	1095.56	1097.67
XS-38	5,331	1094.22	1095.39	1097.64
XS-37	5,182	1094.10	1095.35	1097.63
XS-36	5,058	1094.06	1095.34	1097.63
XS-35	4,968	1094.06	1095.34	1097.62
XS-34	4,890	1094.02	1095.30	1097.60
XS-33	4,778	1093.97	1095.27	1097.58
XS-32	4,663	1093.94	1095.25	1097.57
XS-31	4,579	1093.90	1095.22	1097.55
XS-30	4,515	1086.95	1087.06	1087.23
XS-29	4,496	1086.79	1086.93	1087.12
XS-28	4,383	1086.30	1086.47	1086.69

Table F-1 Flood level sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Embarras River		
XS-27	4,293	1085.77	1085.94	1086.13
XS-26	3,939	1083.96	1084.12	1084.29
XS-25	3,687	1081.88	1082.02	1082.18
XS-24	3,554	1081.40	1081.54	1081.73
XS-23	3,422	1080.97	1081.12	1081.33
XS-22	3,284	1080.38	1080.52	1080.69
XS-21	3,265	1080.08	1080.22	1080.40
XS-20	3,194	1079.67	1079.81	1079.99
XS-19	3,044	1078.92	1079.04	1079.19
XS-18	2,935	1078.42	1078.54	1078.68
XS-17	2,765	1077.94	1078.06	1078.22
XS-16	2,597	1077.33	1077.44	1077.59
XS-15	2,415	1076.51	1076.67	1076.88
XS-14	2,252	1075.86	1076.04	1076.25
XS-13	2,100	1075.29	1075.46	1075.66
XS-12	1,917	1074.64	1074.79	1074.97
XS-11	1,783	1074.02	1074.14	1074.36
XS-10	1,610	1073.51	1073.64	1073.82
XS-9	1,463	1073.00	1073.12	1073.28
XS-8	1,347	1072.36	1072.50	1072.67
XS-7	1,226	1071.98	1072.13	1072.32
XS-6	1,054	1071.47	1071.62	1071.79
XS-5	898	1070.93	1071.11	1071.31
XS-4	617	1069.53	1069.70	1069.90
XS-3	390	1068.17	1068.32	1068.52
XS-2	224	1067.51	1067.67	1067.88
XS-1	0	1066.56	1066.73	1066.94
Average Difference		-0.25	0.00	0.41

Table F-1 Flood level sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
Maximum Difference		-1.32	0.00	2.33
		Bryan Creek		
XS-111	3,352	1122.88	1123.00	1123.15
XS-110	3,222	1122.34	1122.45	1122.58
XS-109	3,162	1121.76	1121.85	1121.97
XS-108	3,044	1121.06	1121.17	1121.31
XS-107	2,870	1120.07	1120.20	1120.37
XS-106	2,707	1119.27	1119.40	1119.56
XS-105	2,510	1118.20	1118.30	1118.43
XS-104	2,329	1117.16	1117.26	1117.39
XS-103	2,198	1116.12	1116.21	1116.34
XS-102	2,013	1114.53	1114.65	1114.80
XS-101	1,811	1112.76	1112.87	1113.01
XS-100	1,653	1111.89	1112.10	1112.39
XS-99	1,470	1111.63	1111.89	1112.24
XS-98	1,387	1111.56	1111.83	1112.19
XS-97	1,319	1107.60	1107.71	1107.84
XS-96	1,084	1105.49	1105.59	1105.71
XS-95	968	1104.38	1104.43	1104.48
XS-94	844	1102.73	1102.86	1103.11
XS-93	740	1102.06	1102.33	1102.74
XS-92	611	1101.97	1102.26	1102.69
XS-91	553	1101.96	1102.25	1102.68
XS-90	510	1098.57	1098.58	1101.35
XS-89	408	1097.11	1098.06	1101.33
XS-88	301	1096.12	1097.98	1101.32
XS-87	245	1096.05	1097.97	1101.32
XS-86	153	1096.05	1097.97	1101.32
XS-85	95	1096.04	1097.96	1101.32

Table F-1 Flood level sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Bryan Creek		
XS-84	8	1094.03	1095.31	1097.60
Average Difference		-0.47	0.00	0.93
Maximum Difference		-1.92	0.00	3.36

Note: * indicates value that have been manually adjusted to eliminate the crossing profiles.

Table F-2 Inundation width sensitivity to upstream boundary conditions

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Embarras River		
XS-83	10,796	114	125	141
XS-82	10,649	141	160	173
XS-81	10,474	145	162	186
XS-80	10,389	215	221	229
XS-79	10,178	256	261	263
XS-78	9,974	89	130	160
XS-77	9,887	30	37	65
XS-76	9,877	38	43	59
XS-75	9,834	33	59	62
XS-74	9,689	62	64	83
XS-73	9,500	186	192	195
XS-72	9,271	47	51	61
XS-71	9,113	49	62	113
XS-70	9,021	54	84	102
XS-69	9,005	57	75	96
XS-68	8,959	49	61	82
XS-67	8,864	99	107	147
XS-66	8,721	45	53	57
XS-65	8,669	86	88	98
XS-64	8,593	31	44	90
XS-63	8,350	43	53	63
XS-62	8,204	65	67	68
XS-61	8,007	22	23	28
XS-60	7,809	23	23	24
XS-59	7,639	16	17	17
XS-58	7,404	52	58	64
XS-57	7,254	40	60	72
XS-56	7,143	138	145	147

Table F-2 Inundation width sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Embarras River		
XS-55	7,036	147	149	149
XS-54	6,926	38	56	71
XS-53	6,867	46	51	58
XS-52	6,856	22	28	59
XS-51	6,832	52	67	80
XS-50	6,738	32	40	78
XS-49	6,609	59	60	61
XS-48	6,557	26	28	32
XS-47	6,541	20	25	36
XS-46	6,487	39	49	77
XS-45	6,358	41	44	46
XS-44	6,225	40	41	42
XS-43	6,086	35	35	36
XS-42	5,928	89	89	90
XS-41	5,777	76	84	89
XS-40	5,647	39	36	66
XS-39	5,463	28	37	93
XS-38	5,331	36	46	90
XS-37	5,182	91	107	166
XS-36	5,058	179	253	260
XS-35	4,968	270	324	332
XS-34	4,890	215	229	275
XS-33	4,778	315	324	333
XS-32	4,663	231	240	259
XS-31	4,579	153	182	234
XS-30	4,515	37	38	40
XS-29	4,496	50	68	82
XS-28	4,383	47	49	73

Table F-2 Inundation width sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Embarras River		
XS-27	4,293	30	36	40
XS-26	3,939	88	97	97
XS-25	3,687	45	63	80
XS-24	3,554	174	182	185
XS-23	3,422	95	96	100
XS-22	3,284	39	40	41
XS-21	3,265	39	42	44
XS-20	3,194	140	154	163
XS-19	3,044	76	83	88
XS-18	2,935	123	123	130
XS-17	2,765	141	163	173
XS-16	2,597	79	89	102
XS-15	2,415	142	144	152
XS-14	2,252	43	49	56
XS-13	2,100	83	113	151
XS-12	1,917	98	148	216
XS-11	1,783	148	163	207
XS-10	1,610	264	288	298
XS-9	1,463	90	119	145
XS-8	1,347	99	129	149
XS-7	1,226	125	144	162
XS-6	1,054	76	79	96
XS-5	898	162	183	201
XS-4	617	22	25	39
XS-3	390	70	73	95
XS-2	224	59	74	115
XS-1	0	56	63	75
Average Difference		-12	0	17

Table F-2 Inundation width sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
Maximum Difference		-73	0	68
		Bryan Creek		
XS-111	3,352	35	38	45
XS-110	3,222	18	23	25
XS-109	3,162	20	22	22
XS-108	3,044	37	37	38
XS-107	2,870	12	15	22
XS-106	2,707	18	21	30
XS-105	2,510	30	31	34
XS-104	2,329	28	29	32
XS-103	2,198	18	21	22
XS-102	2,013	13	14	16
XS-101	1,811	9	10	10
XS-100	1,653	18	21	28
XS-99	1,470	43	47	49
XS-98	1,387	75	83	88
XS-97	1,319	7	7	8
XS-96	1,084	36	41	43
XS-95	968	48	48	49
XS-94	844	20	26	42
XS-93	740	23	26	29
XS-92	611	69	70	72
XS-91	553	42	47	66
XS-90	510	28	28	111
XS-89	408	20	28	63
XS-88	301	10	22	50
XS-87	245	28	47	70
XS-86	153	64	78	96
XS-85	95	93	102	122

Table F-2 Inundation width sensitivity to upstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Flood Frequency Estimates		
		95% Lower Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	95% Upper Limit of Flood Frequency Estimates
		Bryan Creek		
XS-84	8	63	93	102
Average Difference		-6	0	11
Maximum Difference		-30	0	83

Table F-3 Flood level sensitivity to downstream boundary conditions

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
		Embarras River		
XS-83	10,796	1134.05	1134.05	1134.05
XS-82	10,649	1133.38	1133.38	1133.38
XS-81	10,474	1132.64	1132.64	1132.64
XS-80	10,389	1132.21	1132.21	1132.21
XS-79	10,178	1131.49	1131.49	1131.49
XS-78	9,974	1130.49	1130.49	1130.49
XS-77	9,887	1130.16	1130.16	1130.16
XS-76	9,877	1130.02	1130.02	1130.02
XS-75	9,834	1129.61	1129.61	1129.61
XS-74	9,689	1128.81	1128.81	1128.81
XS-73	9,500	1128.17	1128.17	1128.17
XS-72	9,271	1126.65	1126.65	1126.65
XS-71	9,113	1126.06	1126.06	1126.06
XS-70	9,021	1125.62	1125.62	1125.62
XS-69	9,005	1125.47	1125.47	1125.47
XS-68	8,959	1125.21	1125.21	1125.21
XS-67	8,864	1124.97	1124.97	1124.97
XS-66	8,721	1124.14	1124.14	1124.14
XS-65	8,669	1123.65	1123.65	1123.65
XS-64	8,593	1123.17	1123.17	1123.17
XS-63	8,350	1121.62	1121.62	1121.62
XS-62	8,204	1120.61	1120.61	1120.61
XS-61	8,007	1118.10	1118.10	1118.10
XS-60	7,809	1115.09	1115.09	1115.09
XS-59	7,639	1112.69	1112.69	1112.69
XS-58	7,404	1109.41	1109.41	1109.41
XS-57	7,254	1108.19	1108.19	1108.19
XS-56	7,143	1107.32	1107.32	1107.32

Table F-3 Flood level sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
		Embarras River		
XS-55	7,036	1106.45	1106.45	1106.45
XS-54	6,926	1105.51	1105.51	1105.51
XS-53	6,867	1105.07	1105.07	1105.07
XS-52	6,856	1104.90	1104.90	1104.90
XS-51	6,832	1104.69	1104.69	1104.69
XS-50	6,738	1104.02	1104.02	1104.02
XS-49	6,609	1103.38	1103.38	1103.38
XS-48	6,557	1103.05	1103.05	1103.05
XS-47	6,541	1102.93	1102.93	1102.93
XS-46	6,487	1102.64	1102.64	1102.64
XS-45	6,358	1101.72	1101.72	1101.72
XS-44	6,225	1100.90	1100.90	1100.90
XS-43	6,086	1099.93	1099.93	1099.93
XS-42	5,928	1098.79	1098.79	1098.79
XS-41	5,777	1097.87	1097.87	1097.87
XS-40	5,647	1096.69*	1096.69*	1096.69*
XS-39	5,463	1095.56	1095.56	1095.56
XS-38	5,331	1095.39	1095.39	1095.39
XS-37	5,182	1095.35	1095.35	1095.35
XS-36	5,058	1095.34	1095.34	1095.34
XS-35	4,968	1095.34	1095.34	1095.34
XS-34	4,890	1095.30	1095.30	1095.30
XS-33	4,778	1095.27	1095.27	1095.27
XS-32	4,663	1095.25	1095.25	1095.25
XS-31	4,579	1095.22	1095.22	1095.22
XS-30	4,515	1087.06	1087.06	1087.06
XS-29	4,496	1086.93	1086.93	1086.93
XS-28	4,383	1086.47	1086.47	1086.47

Table F-3 Flood level sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
		Embarras River		
XS-27	4,293	1085.94	1085.94	1085.94
XS-26	3,939	1084.12	1084.12	1084.12
XS-25	3,687	1082.02	1082.02	1082.02
XS-24	3,554	1081.54	1081.54	1081.54
XS-23	3,422	1081.12	1081.12	1081.12
XS-22	3,284	1080.52	1080.52	1080.52
XS-21	3,265	1080.22	1080.22	1080.22
XS-20	3,194	1079.81	1079.81	1079.81
XS-19	3,044	1079.04	1079.04	1079.04
XS-18	2,935	1078.54	1078.54	1078.54
XS-17	2,765	1078.06	1078.06	1078.06
XS-16	2,597	1077.44	1077.44	1077.44
XS-15	2,415	1076.67	1076.67	1076.67
XS-14	2,252	1076.04	1076.04	1076.04
XS-13	2,100	1075.46	1075.46	1075.46
XS-12	1,917	1074.79	1074.79	1074.79
XS-11	1,783	1074.14	1074.14	1074.14
XS-10	1,610	1073.64	1073.64	1073.64
XS-9	1,463	1073.12	1073.12	1073.12
XS-8	1,347	1072.50	1072.50	1072.50
XS-7	1,226	1072.13	1072.13	1072.13
XS-6	1,054	1071.62	1071.62	1071.62
XS-5	898	1071.11	1071.11	1071.11
XS-4	617	1069.70	1069.70	1069.70
XS-3	390	1068.32	1068.32	1068.33
XS-2	224	1067.67	1067.67	1067.72
XS-1	0	1066.43	1066.73	1067.03
Average Difference		0.00	0.00	0.00

Table F-3 Flood level sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
Maximum Difference		-0.30	0.00	0.30
		Bryan Creek		
XS-111	3,352	1123.00	1123.00	1123.00
XS-110	3,222	1122.45	1122.45	1122.45
XS-109	3,162	1121.85	1121.85	1121.85
XS-108	3,044	1121.17	1121.17	1121.17
XS-107	2,870	1120.20	1120.20	1120.20
XS-106	2,707	1119.40	1119.40	1119.40
XS-105	2,510	1118.30	1118.30	1118.30
XS-104	2,329	1117.26	1117.26	1117.26
XS-103	2,198	1116.21	1116.21	1116.21
XS-102	2,013	1114.65	1114.65	1114.65
XS-101	1,811	1112.87	1112.87	1112.87
XS-100	1,653	1112.10	1112.10	1112.10
XS-99	1,470	1111.89	1111.89	1111.89
XS-98	1,387	1111.83	1111.83	1111.83
XS-97	1,319	1107.71	1107.71	1107.71
XS-96	1,084	1105.59	1105.59	1105.59
XS-95	968	1104.43	1104.43	1104.43
XS-94	844	1102.86	1102.86	1102.86
XS-93	740	1102.33	1102.33	1102.33
XS-92	611	1102.26	1102.26	1102.26
XS-91	553	1102.25	1102.25	1102.25
XS-90	510	1098.58	1098.58	1098.58
XS-89	408	1098.06	1098.06	1098.06
XS-88	301	1097.98	1097.98	1097.98
XS-87	245	1097.97	1097.97	1097.97
XS-86	153	1097.97	1097.97	1097.97
XS-85	95	1097.96	1097.96	1097.96

Table F-3 Flood level sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
		Bryan Creek		
XS-84	8	1095.31	1095.31	1095.31
Average Difference		0.00	0.00	0.00
Maximum Difference		0.00	0.00	0.00

Note: * indicates value that have been manually adjusted to eliminate the crossing profiles.

Table F-4 Inundation width sensitivity to downstream boundary conditions

Cross Section Number	River Station (m)	100-Year Inundation width (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
		Embarras River		
XS-83	10,796	125	125	125
XS-82	10,649	160	160	160
XS-81	10,474	162	162	162
XS-80	10,389	221	221	221
XS-79	10,178	261	261	261
XS-78	9,974	130	130	130
XS-77	9,887	37	37	37
XS-76	9,877	43	43	43
XS-75	9,834	59	59	59
XS-74	9,689	64	64	64
XS-73	9,500	192	192	192
XS-72	9,271	51	51	51
XS-71	9,113	62	62	62
XS-70	9,021	84	84	84
XS-69	9,005	75	75	75
XS-68	8,959	61	61	61
XS-67	8,864	107	107	107
XS-66	8,721	53	53	53
XS-65	8,669	88	88	88
XS-64	8,593	44	44	44
XS-63	8,350	53	53	53
XS-62	8,204	67	67	67
XS-61	8,007	23	23	23
XS-60	7,809	23	23	23
XS-59	7,639	17	17	17
XS-58	7,404	58	58	58
XS-57	7,254	60	60	60
XS-56	7,143	145	145	145

Table F-4 Inundation width sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation width (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
Embarras River				
XS-55	7,036	149	149	149
XS-54	6,926	56	56	56
XS-53	6,867	51	51	51
XS-52	6,856	28	28	28
XS-51	6,832	67	67	67
XS-50	6,738	40	40	40
XS-49	6,609	60	60	60
XS-48	6,557	28	28	28
XS-47	6,541	25	25	25
XS-46	6,487	49	49	49
XS-45	6,358	44	44	44
XS-44	6,225	41	41	41
XS-43	6,086	35	35	35
XS-42	5,928	89	89	89
XS-41	5,777	84	84	84
XS-40	5,647	36	36	36
XS-39	5,463	37	37	37
XS-38	5,331	46	46	46
XS-37	5,182	107	107	107
XS-36	5,058	253	253	253
XS-35	4,968	324	324	324
XS-34	4,890	229	229	229
XS-33	4,778	324	324	324
XS-32	4,663	240	240	240
XS-31	4,579	182	182	182
XS-30	4,515	38	38	38
XS-29	4,496	68	68	68
XS-28	4,383	49	49	49

Table F-4 Inundation width sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation width (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
Embarras River				
XS-27	4,293	36	36	36
XS-26	3,939	97	97	97
XS-25	3,687	63	63	63
XS-24	3,554	182	182	182
XS-23	3,422	96	96	96
XS-22	3,284	40	40	40
XS-21	3,265	42	42	42
XS-20	3,194	154	154	154
XS-19	3,044	83	83	83
XS-18	2,935	123	123	123
XS-17	2,765	163	163	163
XS-16	2,597	89	89	89
XS-15	2,415	144	144	144
XS-14	2,252	49	49	49
XS-13	2,100	113	113	113
XS-12	1,917	148	148	148
XS-11	1,783	163	163	163
XS-10	1,610	288	288	288
XS-9	1,463	119	119	119
XS-8	1,347	129	129	129
XS-7	1,226	144	144	144
XS-6	1,054	79	79	79
XS-5	898	183	183	183
XS-4	617	25	25	25
XS-3	390	73	73	74
XS-2	224	74	74	80
XS-1	0	48	63	84
Average Difference		0	0	0

Table F-4 Inundation width sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation width (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
Maximum Difference		-15	0	21
		Bryan Creek		
XS-111	3,352	38	38	38
XS-110	3,222	23	23	23
XS-109	3,162	22	22	22
XS-108	3,044	37	37	37
XS-107	2,870	15	15	15
XS-106	2,707	21	21	21
XS-105	2,510	31	31	31
XS-104	2,329	29	29	29
XS-103	2,198	21	21	21
XS-102	2,013	14	14	14
XS-101	1,811	10	10	10
XS-100	1,653	21	21	21
XS-99	1,470	47	47	47
XS-98	1,387	83	83	83
XS-97	1,319	7	7	7
XS-96	1,084	41	41	41
XS-95	968	48	48	48
XS-94	844	26	26	26
XS-93	740	26	26	26
XS-92	611	70	70	70
XS-91	553	47	47	47
XS-90	510	28	28	28
XS-89	408	28	28	28
XS-88	301	22	22	22
XS-87	245	47	47	47
XS-86	153	78	78	78
XS-85	95	102	102	102

Table F-4 Inundation width sensitivity to downstream boundary conditions (Continued)

Cross Section Number	River Station (m)	100-Year Inundation width (m) for Varying Downstream Boundary Conditions		
		0.3 m Below Adopted W.S. (W. S. =1066.43 m)	Adopted W.S.=1066.73 m	0.3 m Above Adopted W.S. (W. S. = 1067.03 m)
Bryan Creek				
XS-84	8	93	93	93
Average Difference		0	0	0
Maximum Difference		0	0	0

Table F-5 Flood level sensitivity to channel roughness

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Embarras River		
XS-83	10,796	1133.91	1134.05	1134.15
XS-82	10,649	1133.28	1133.38	1133.47
XS-81	10,474	1132.55	1132.64	1132.72
XS-80	10,389	1132.14	1132.21	1132.27
XS-79	10,178	1131.43	1131.49	1131.53
XS-78	9,974	1130.31	1130.49	1130.64
XS-77	9,887	1130.03	1130.16	1130.27
XS-76	9,877	1129.88	1130.02	1130.14
XS-75	9,834	1129.44	1129.61	1129.75
XS-74	9,689	1128.71	1128.81	1128.88
XS-73	9,500	1128.14	1128.17	1128.19
XS-72	9,271	1126.41	1126.65	1126.82
XS-71	9,113	1125.90	1126.06	1126.19
XS-70	9,021	1125.46	1125.62	1125.76
XS-69	9,005	1125.32	1125.47	1125.60
XS-68	8,959	1125.08	1125.21	1125.33
XS-67	8,864	1124.88	1124.97	1125.06
XS-66	8,721	1124.00	1124.14	1124.26
XS-65	8,669	1123.52	1123.65	1123.76
XS-64	8,593	1123.02	1123.17	1123.31
XS-63	8,350	1121.48	1121.62	1121.75
XS-62	8,204	1120.48	1120.61	1120.71
XS-61	8,007	1117.97	1118.10	1118.22
XS-60	7,809	1114.92	1115.09	1115.25
XS-59	7,639	1112.57	1112.69	1112.79
XS-58	7,404	1109.23	1109.41	1109.56
XS-57	7,254	1108.03	1108.19	1108.29
XS-56	7,143	1107.21	1107.32	1107.39

Table F-5 Flood level sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Embarras River		
XS-55	7,036	1106.33	1106.45	1106.54
XS-54	6,926	1105.34	1105.51	1105.66
XS-53	6,867	1104.92	1105.07	1105.20
XS-52	6,856	1104.72	1104.90	1105.04
XS-51	6,832	1104.49	1104.69	1104.85
XS-50	6,738	1103.88	1104.02	1104.15
XS-49	6,609	1103.19	1103.38	1103.54
XS-48	6,557	1102.88	1103.05	1103.20
XS-47	6,541	1102.76	1102.93	1103.08
XS-46	6,487	1102.49	1102.64	1102.78
XS-45	6,358	1101.54	1101.72	1101.87
XS-44	6,225	1100.75	1100.90	1101.04
XS-43	6,086	1099.79	1099.93	1100.05
XS-42	5,928	1098.68	1098.79	1098.88
XS-41	5,777	1097.75	1097.87	1097.97
XS-40	5,647	1096.48	1096.69*	1096.83
XS-39	5,463	1095.48	1095.56	1095.63
XS-38	5,331	1095.35	1095.39	1095.43
XS-37	5,182	1095.32	1095.35	1095.37
XS-36	5,058	1095.31	1095.34	1095.36
XS-35	4,968	1095.31	1095.34	1095.36
XS-34	4,890	1095.28	1095.30	1095.33
XS-33	4,778	1095.26	1095.27	1095.28
XS-32	4,663	1095.25	1095.25	1095.26
XS-31	4,579	1095.22	1095.22	1095.22
XS-30	4,515	1086.94	1087.06	1087.22
XS-29	4,496	1086.73	1086.93	1087.10
XS-28	4,383	1086.31	1086.47	1086.63

Table F-5 Flood level sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Embarras River		
XS-27	4,293	1085.71	1085.94	1086.12
XS-26	3,939	1083.97	1084.12	1084.23
XS-25	3,687	1081.87	1082.02	1082.13
XS-24	3,554	1081.44	1081.54	1081.64
XS-23	3,422	1080.95	1081.12	1081.26
XS-22	3,284	1080.38	1080.52	1080.63
XS-21	3,265	1080.08	1080.22	1080.34
XS-20	3,194	1079.63	1079.81	1079.96
XS-19	3,044	1078.89	1079.04	1079.16
XS-18	2,935	1078.39	1078.54	1078.64
XS-17	2,765	1077.94	1078.06	1078.16
XS-16	2,597	1077.32	1077.44	1077.54
XS-15	2,415	1076.47	1076.67	1076.83
XS-14	2,252	1075.84	1076.04	1076.20
XS-13	2,100	1075.26	1075.46	1075.62
XS-12	1,917	1074.63	1074.79	1074.92
XS-11	1,783	1074.00	1074.14	1074.26
XS-10	1,610	1073.51	1073.64	1073.74
XS-9	1,463	1072.99	1073.12	1073.24
XS-8	1,347	1072.31	1072.50	1072.64
XS-7	1,226	1071.97	1072.13	1072.26
XS-6	1,054	1071.45	1071.62	1071.75
XS-5	898	1070.91	1071.11	1071.26
XS-4	617	1069.49	1069.70	1069.88
XS-3	390	1068.14	1068.32	1068.48
XS-2	224	1067.49	1067.67	1067.83
XS-1	0	1066.53	1066.73	1066.90
Average Difference		-0.14	0.00	0.11

Table F-5 Flood level sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
Maximum Difference		-0.24	0.00	0.18
		Bryan Creek		
XS-111	3,352	1122.89	1123.00	1123.09
XS-110	3,222	1122.37	1122.45	1122.53
XS-109	3,162	1121.71	1121.85	1121.96
XS-108	3,044	1121.05	1121.17	1121.27
XS-107	2,870	1120.04	1120.20	1120.34
XS-106	2,707	1119.27	1119.40	1119.52
XS-105	2,510	1118.16	1118.30	1118.41
XS-104	2,329	1117.17	1117.26	1117.35
XS-103	2,198	1116.07	1116.21	1116.33
XS-102	2,013	1114.54	1114.65	1114.76
XS-101	1,811	1112.69	1112.87	1113.02
XS-100	1,653	1112.04	1112.10	1112.15
XS-99	1,470	1111.87	1111.89	1111.91
XS-98	1,387	1111.83	1111.83	1111.83
XS-97	1,319	1107.53	1107.71	1107.87
XS-96	1,084	1105.51	1105.59	1105.65
XS-95	968	1104.35	1104.43	1104.50
XS-94	844	1102.73	1102.86	1102.98
XS-93	740	1102.29	1102.33	1102.37
XS-92	611	1102.26	1102.26	1102.27
XS-91	553	1102.25	1102.25	1102.25
XS-90	510	1098.44	1098.58	1098.70
XS-89	408	1098.02	1098.06	1098.12
XS-88	301	1097.95	1097.98	1098.01
XS-87	245	1097.95	1097.97	1098.00
XS-86	153	1097.95	1097.97	1097.99
XS-85	95	1097.94	1097.96	1097.99

Table F-5 Flood level sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Bryan Creek		
XS-84	8	1095.29	1095.31	1095.33
Average Difference		-0.08	0.00	0.07
Maximum Difference		-0.18	0.00	0.16

Note: * indicates value that have been manually adjusted to eliminate the crossing profiles.

Table F-6 Inundation width sensitivity to channel roughness

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Embarras River		
XS-83	10,796	111	125	136
XS-82	10,649	142	160	169
XS-81	10,474	144	162	182
XS-80	10,389	215	221	226
XS-79	10,178	258	261	262
XS-78	9,974	86	130	156
XS-77	9,887	32	37	51
XS-76	9,877	38	43	49
XS-75	9,834	30	59	62
XS-74	9,689	63	64	73
XS-73	9,500	191	192	193
XS-72	9,271	41	51	61
XS-71	9,113	49	62	94
XS-70	9,021	46	84	97
XS-69	9,005	55	75	93
XS-68	8,959	46	61	79
XS-67	8,864	100	107	131
XS-66	8,721	42	53	58
XS-65	8,669	86	88	95
XS-64	8,593	30	44	79
XS-63	8,350	41	53	62
XS-62	8,204	65	67	68
XS-61	8,007	22	23	28
XS-60	7,809	22	23	24
XS-59	7,639	16	17	17
XS-58	7,404	50	58	63
XS-57	7,254	39	60	71
XS-56	7,143	137	145	147

Table F-6 Inundation width sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Embarras River		
XS-55	7,036	145	149	149
XS-54	6,926	37	56	70
XS-53	6,867	47	51	55
XS-52	6,856	22	28	49
XS-51	6,832	49	67	78
XS-50	6,738	32	40	72
XS-49	6,609	59	60	60
XS-48	6,557	25	28	31
XS-47	6,541	19	25	32
XS-46	6,487	39	49	63
XS-45	6,358	40	44	46
XS-44	6,225	40	41	42
XS-43	6,086	35	35	36
XS-42	5,928	89	89	90
XS-41	5,777	77	84	87
XS-40	5,647	24	36	53
XS-39	5,463	37	37	37
XS-38	5,331	45	46	47
XS-37	5,182	106	107	108
XS-36	5,058	253	253	253
XS-35	4,968	324	324	324
XS-34	4,890	229	229	229
XS-33	4,778	324	324	324
XS-32	4,663	240	240	240
XS-31	4,579	182	182	182
XS-30	4,515	37	38	39
XS-29	4,496	42	68	82
XS-28	4,383	47	49	67

Table F-6 Inundation width sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Embarras River		
XS-27	4,293	28	36	40
XS-26	3,939	88	97	97
XS-25	3,687	44	63	73
XS-24	3,554	176	182	184
XS-23	3,422	95	96	98
XS-22	3,284	39	40	41
XS-21	3,265	40	42	44
XS-20	3,194	135	154	162
XS-19	3,044	73	83	88
XS-18	2,935	123	123	129
XS-17	2,765	143	163	171
XS-16	2,597	79	89	99
XS-15	2,415	141	144	146
XS-14	2,252	42	49	55
XS-13	2,100	77	113	147
XS-12	1,917	97	148	205
XS-11	1,783	146	163	188
XS-10	1,610	264	288	297
XS-9	1,463	88	119	138
XS-8	1,347	92	129	146
XS-7	1,226	123	144	155
XS-6	1,054	75	79	93
XS-5	898	160	183	194
XS-4	617	22	25	37
XS-3	390	69	73	89
XS-2	224	54	74	102
XS-1	0	54	63	73
Average Difference		-10	0	10

Table F-6 Inundation width sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
Maximum Difference		-51	0	57
		Bryan Creek		
XS-111	3,352	35	38	43
XS-110	3,222	20	23	24
XS-109	3,162	18	22	22
XS-108	3,044	37	37	38
XS-107	2,870	12	15	21
XS-106	2,707	18	21	27
XS-105	2,510	29	31	34
XS-104	2,329	28	29	31
XS-103	2,198	17	21	22
XS-102	2,013	13	14	16
XS-101	1,811	8	10	10
XS-100	1,653	20	21	22
XS-99	1,470	47	47	48
XS-98	1,387	83	83	83
XS-97	1,319	7	7	8
XS-96	1,084	37	41	42
XS-95	968	47	48	50
XS-94	844	20	26	37
XS-93	740	26	26	27
XS-92	611	70	70	70
XS-91	553	47	47	47
XS-90	510	21	28	31
XS-89	408	27	28	28
XS-88	301	22	22	22
XS-87	245	47	47	47
XS-86	153	78	78	79
XS-85	95	102	102	102

Table F-6 Inundation width sensitivity to channel roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
		Bryan Creek		
XS-84	8	93	93	94
Average Difference		-2	0	2
Maximum Difference		-7	0	11

Table F-7 Flood level sensitivity to overbank roughness

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
		Embarras River		
XS-83	10,796	1134.01	1134.05	1134.08
XS-82	10,649	1133.35	1133.38	1133.41
XS-81	10,474	1132.61	1132.64	1132.67
XS-80	10,389	1132.17	1132.21	1132.25
XS-79	10,178	1131.45	1131.49	1131.52
XS-78	9,974	1130.49	1130.49	1130.49
XS-77	9,887	1130.15	1130.16	1130.17
XS-76	9,877	1130.01	1130.02	1130.02
XS-75	9,834	1129.58	1129.61	1129.64
XS-74	9,689	1128.73	1128.81	1128.86
XS-73	9,500	1128.10	1128.17	1128.22
XS-72	9,271	1126.65	1126.65	1126.65
XS-71	9,113	1126.05	1126.06	1126.06
XS-70	9,021	1125.62	1125.62	1125.62
XS-69	9,005	1125.47	1125.47	1125.47
XS-68	8,959	1125.20	1125.21	1125.21
XS-67	8,864	1124.96	1124.97	1124.98
XS-66	8,721	1124.14	1124.14	1124.13
XS-65	8,669	1123.64	1123.65	1123.65
XS-64	8,593	1123.17	1123.17	1123.17
XS-63	8,350	1121.61	1121.62	1121.64
XS-62	8,204	1120.60	1120.61	1120.61
XS-61	8,007	1118.09	1118.10	1118.10
XS-60	7,809	1115.10	1115.09	1115.09
XS-59	7,639	1112.67	1112.69	1112.70
XS-58	7,404	1109.41	1109.41	1109.42
XS-57	7,254	1108.19	1108.19	1108.19
XS-56	7,143	1107.31	1107.32	1107.33

Table F-7 Flood level sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
		Embarras River		
XS-55	7,036	1106.44	1106.45	1106.46
XS-54	6,926	1105.50	1105.51	1105.51
XS-53	6,867	1105.06	1105.07	1105.08
XS-52	6,856	1104.89	1104.90	1104.91
XS-51	6,832	1104.68	1104.69	1104.70
XS-50	6,738	1103.99	1104.02	1104.05
XS-49	6,609	1103.38	1103.38	1103.38
XS-48	6,557	1103.04	1103.05	1103.06
XS-47	6,541	1102.92	1102.93	1102.94
XS-46	6,487	1102.63	1102.64	1102.65
XS-45	6,358	1101.71	1101.72	1101.72
XS-44	6,225	1100.89	1100.90	1100.91
XS-43	6,086	1099.92	1099.93	1099.94
XS-42	5,928	1098.76	1098.79	1098.81
XS-41	5,777	1097.86	1097.87	1097.88
XS-40	5,647	1096.65	1096.69*	1096.69*
XS-39	5,463	1095.54	1095.56	1095.57
XS-38	5,331	1095.38	1095.39	1095.39
XS-37	5,182	1095.34	1095.35	1095.35
XS-36	5,058	1095.34	1095.34	1095.34
XS-35	4,968	1095.34	1095.34	1095.34
XS-34	4,890	1095.30	1095.30	1095.30
XS-33	4,778	1095.27	1095.27	1095.27
XS-32	4,663	1095.25	1095.25	1095.25
XS-31	4,579	1095.22	1095.22	1095.22
XS-30	4,515	1087.05	1087.06	1087.06
XS-29	4,496	1086.93	1086.93	1086.93
XS-28	4,383	1086.46	1086.47	1086.48

Table F-7 Flood level sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
		Embarras River		
XS-27	4,293	1085.92	1085.94	1085.95
XS-26	3,939	1084.10	1084.12	1084.13
XS-25	3,687	1081.98	1082.02	1082.04
XS-24	3,554	1081.50	1081.54	1081.58
XS-23	3,422	1081.10	1081.12	1081.14
XS-22	3,284	1080.50	1080.52	1080.53
XS-21	3,265	1080.20	1080.22	1080.24
XS-20	3,194	1079.80	1079.81	1079.82
XS-19	3,044	1079.02	1079.04	1079.05
XS-18	2,935	1078.51	1078.54	1078.56
XS-17	2,765	1078.03	1078.06	1078.08
XS-16	2,597	1077.41	1077.44	1077.47
XS-15	2,415	1076.66	1076.67	1076.67
XS-14	2,252	1076.02	1076.04	1076.05
XS-13	2,100	1075.45	1075.46	1075.47
XS-12	1,917	1074.77	1074.79	1074.81
XS-11	1,783	1074.09	1074.14	1074.18
XS-10	1,610	1073.60	1073.64	1073.66
XS-9	1,463	1073.10	1073.12	1073.14
XS-8	1,347	1072.47	1072.50	1072.51
XS-7	1,226	1072.11	1072.13	1072.14
XS-6	1,054	1071.60	1071.62	1071.63
XS-5	898	1071.10	1071.11	1071.12
XS-4	617	1069.69	1069.70	1069.71
XS-3	390	1068.30	1068.32	1068.34
XS-2	224	1067.66	1067.67	1067.68
XS-1	0	1066.72	1066.73	1066.73
Average Difference		-0.02	0.00	0.01

Table F-7 Flood level sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
Maximum Difference		-0.08	0.00	0.05
		Bryan Creek		
XS-111	3,352	1122.98	1123.00	1123.02
XS-110	3,222	1122.43	1122.45	1122.47
XS-109	3,162	1121.84	1121.85	1121.86
XS-108	3,044	1121.16	1121.17	1121.18
XS-107	2,870	1120.20	1120.20	1120.21
XS-106	2,707	1119.39	1119.40	1119.41
XS-105	2,510	1118.28	1118.30	1118.31
XS-104	2,329	1117.25	1117.26	1117.27
XS-103	2,198	1116.21	1116.21	1116.22
XS-102	2,013	1114.65	1114.65	1114.65
XS-101	1,811	1112.87	1112.87	1112.87
XS-100	1,653	1112.06	1112.10	1112.13
XS-99	1,470	1111.89	1111.89	1111.89
XS-98	1,387	1111.83	1111.83	1111.83
XS-97	1,319	1107.70	1107.71	1107.71
XS-96	1,084	1105.58	1105.59	1105.60
XS-95	968	1104.42	1104.43	1104.43
XS-94	844	1102.86	1102.86	1102.86
XS-93	740	1102.33	1102.33	1102.33
XS-92	611	1102.26	1102.26	1102.26
XS-91	553	1102.25	1102.25	1102.25
XS-90	510	1098.58	1098.58	1098.58
XS-89	408	1098.06	1098.06	1098.06
XS-88	301	1097.98	1097.98	1097.98
XS-87	245	1097.97	1097.97	1097.97
XS-86	153	1097.97	1097.97	1097.97
XS-85	95	1097.96	1097.96	1097.96

Table F-7 Flood level sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
Bryan Creek				
XS-84	8	1095.31	1095.31	1095.31
Average Difference		-0.01	0.00	0.01
Maximum Difference		-0.04	0.00	0.03

Note: * indicates value that have been manually adjusted to eliminate the crossing profiles.

Table F-8 Inundation width sensitivity to overbank roughness

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
Embarras River				
XS-83	10,796	120	125	128
XS-82	10,649	156	160	163
XS-81	10,474	157	162	169
XS-80	10,389	217	221	226
XS-79	10,178	259	261	262
XS-78	9,974	129	130	132
XS-77	9,887	37	37	37
XS-76	9,877	42	43	43
XS-75	9,834	53	59	60
XS-74	9,689	63	64	68
XS-73	9,500	188	192	193
XS-72	9,271	51	51	51
XS-71	9,113	61	62	62
XS-70	9,021	84	84	84
XS-69	9,005	75	75	76
XS-68	8,959	61	61	62
XS-67	8,864	105	107	109
XS-66	8,721	54	53	53
XS-65	8,669	88	88	88
XS-64	8,593	43	44	45
XS-63	8,350	52	53	54
XS-62	8,204	66	67	67
XS-61	8,007	23	23	23
XS-60	7,809	23	23	23
XS-59	7,639	17	17	17
XS-58	7,404	58	58	58
XS-57	7,254	60	60	60
XS-56	7,143	144	145	145

Table F-8 Inundation width sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
		Embarras River		
XS-55	7,036	149	149	149
XS-54	6,926	56	56	57
XS-53	6,867	51	51	51
XS-52	6,856	27	28	30
XS-51	6,832	65	67	67
XS-50	6,738	38	40	43
XS-49	6,609	60	60	60
XS-48	6,557	28	28	28
XS-47	6,541	24	25	25
XS-46	6,487	48	49	51
XS-45	6,358	44	44	44
XS-44	6,225	41	41	41
XS-43	6,086	35	35	35
XS-42	5,928	89	89	90
XS-41	5,777	83	84	85
XS-40	5,647	34	36	37
XS-39	5,463	37	37	37
XS-38	5,331	46	46	46
XS-37	5,182	107	107	107
XS-36	5,058	253	253	253
XS-35	4,968	324	324	324
XS-34	4,890	229	229	229
XS-33	4,778	324	324	324
XS-32	4,663	240	240	240
XS-31	4,579	182	182	182
XS-30	4,515	38	38	38
XS-29	4,496	67	68	68
XS-28	4,383	49	49	50

Table F-8 Inundation width sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
		Embarras River		
XS-27	4,293	35	36	36
XS-26	3,939	96	97	97
XS-25	3,687	59	63	64
XS-24	3,554	180	182	183
XS-23	3,422	96	96	96
XS-22	3,284	40	40	40
XS-21	3,265	42	42	43
XS-20	3,194	153	154	155
XS-19	3,044	82	83	84
XS-18	2,935	123	123	124
XS-17	2,765	159	163	168
XS-16	2,597	87	89	91
XS-15	2,415	143	144	144
XS-14	2,252	49	49	49
XS-13	2,100	110	113	114
XS-12	1,917	141	148	155
XS-11	1,783	155	163	171
XS-10	1,610	284	288	290
XS-9	1,463	114	119	121
XS-8	1,347	123	129	132
XS-7	1,226	142	144	145
XS-6	1,054	79	79	80
XS-5	898	182	183	184
XS-4	617	25	25	25
XS-3	390	72	73	74
XS-2	224	74	74	76
XS-1	0	63	63	63
Average Difference		-1	0	1

Table F-8 Inundation width sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
Maximum Difference		-7	0	9
		Bryan Creek		
XS-111	3,352	38	38	39
XS-110	3,222	23	23	23
XS-109	3,162	22	22	22
XS-108	3,044	37	37	37
XS-107	2,870	15	15	15
XS-106	2,707	21	21	22
XS-105	2,510	31	31	31
XS-104	2,329	29	29	30
XS-103	2,198	21	21	21
XS-102	2,013	14	14	14
XS-101	1,811	10	10	10
XS-100	1,653	21	21	22
XS-99	1,470	47	47	47
XS-98	1,387	83	83	83
XS-97	1,319	7	7	7
XS-96	1,084	41	41	41
XS-95	968	48	48	48
XS-94	844	26	26	26
XS-93	740	26	26	26
XS-92	611	70	70	70
XS-91	553	47	47	47
XS-90	510	28	28	28
XS-89	408	28	28	28
XS-88	301	22	22	22
XS-87	245	47	47	47
XS-86	153	78	78	78
XS-85	95	102	102	102

Table F-8 Inundation width sensitivity to overbank roughness (Continued)

Cross Section Number	River Station (m)	100-Year Inundation Width (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
		Bryan Creek		
XS-84	8	93	93	93
Average Difference		0	0	0
Maximum Difference		-1	0	1

September 2025

APPENDIX G

OPEN WATER FLOOD INUNDATION MAP LIBRARY

(provided under separate cover)

Robb Flood Study
Main Report

September 2025

APPENDIX H

FLOODWAY DETERMINATION CRITERIA AND DESIGN FLOOD LEVELS

Robb Flood Study
Main Report

Table H-1 Floodway Limits and Determination Criteria

River	Cross Section Number	River Station (m)	Left Floodway Limit	Left Determining Criteria	Right Floodway Limit	Right Determining Criteria
Embarras River	XS-83	10796	64.2	1 m Depth	83.3	1 m/s Velocity
	XS-82	10649	56.3	1 m Depth	83.8	1 m Depth
	XS-81	10474	22.9	Inundation Extent[1]	42.1	1 m/s Velocity
	XS-80	10389	10.3	Main Channel	24.9	1 m Depth
	XS-79	10178	72.6	Inundation Extent[1]	117.0	1 m Depth
	XS-78	9974	221.8	1 m Depth	249.1	1 m Depth
	XS-77	9887	202.7	Inundation Extent[1]	226.0	Inundation Extent[1]
	XS-76	9877	218.5	Main Channel	240.3	Inundation Extent[1]
	XS-75	9834	223.4	1 m/s Velocity	241.6	Main Channel
	XS-74	9689	160.4	Main Channel	210.6	1 m Depth
	XS-73	9500	209.2	1 m Depth	250.5	1 m Depth
	XS-72	9271	294.7	1 m/s Velocity	308.2	Main Channel
	XS-71	9113	240.7	Main Channel	270.3	1 m Depth
	XS-70	9021	260.7	1 m/s Velocity	284.2	Main Channel
	XS-69	9005	256.7	Main Channel	278.1	Main Channel
	XS-68	8959	259.7	Main Channel	291.2	Main Channel
	XS-67	8864	178.3	Main Channel	225.0	Main Channel
	XS-66	8721	119.1	Inundation Extent[1]	228.9	Main Channel
	XS-65	8669	25.0	Inundation Extent[1]	230.9	Inundation Extent[1]
	XS-64	8593	151.8	Main Channel	180.6	Inundation Extent[1]
	XS-63	8350	81.5	1 m Depth	107.9	Inundation Extent[1]
	XS-62	8204	47.0	Inundation Extent[1]	66.0	Main Channel
	XS-61	8007	144.6	Main Channel	167.9	Inundation Extent[1]
	XS-60	7809	32.8	Inundation Extent[1]	56.0	Inundation Extent[1]
	XS-59	7639	38.8	Inundation Extent[1]	55.4	Main Channel
	XS-58	7404	86.1	1 m/s Velocity	103.6	Main Channel
	XS-57	7254	77.8	Main Channel	100.8	Main Channel
	XS-56	7143	106.6	1 m/s Velocity	122.6	1 m Depth
	XS-55	7036	94.6	1 m/s Velocity	115.3	1 m/s Velocity
	XS-54	6926	71.8	1 m/s Velocity	92.4	Main Channel

Table H-1 Floodway Limits and Determination Criteria (Continued)

River	Cross Section Number	River Station (m)	Left Floodway Limit	Left Determining Criteria	Right Floodway Limit	Right Determining Criteria
Embarras River	XS-53	6867	28.0	1 m Depth	67.3	Main Channel
	XS-52	6856	7.6	1 m Depth	62.5	Main Channel
	XS-51	6832	15.7	Inundation Extent[1]	55.6	1 m/s Velocity
	XS-50	6738	20.8	Main Channel	38.5	1 m/s Velocity
	XS-49	6609	36.9	Main Channel	52.9	1 m Depth
	XS-48	6557	70.6	Main Channel	90.3	Main Channel
	XS-47	6541	67.3	Inundation Extent[1]	87.4	Inundation Extent[1]
	XS-46	6487	100.2	1 m Depth	121.0	1 m Depth
	XS-45	6358	29.8	Inundation Extent[1]	47.1	1 m/s Velocity
	XS-44	6225	71.8	Inundation Extent[1]	91.2	1 m/s Velocity
	XS-43	6086	74.7	1 m/s Velocity	92.2	Main Channel
	XS-42	5928	65.5	Inundation Extent[1]	82.7	1 m/s Velocity
	XS-41	5777	94.2	Main Channel	115.9	1 m/s Velocity
	XS-40	5647	118.1	Inundation Extent[1]	138.6	1 m/s Velocity
	XS-39	5463	141.1	1 m Depth	174.3	Inundation Extent[1]
	XS-38	5331	93.1	1 m Depth	131.2	Inundation Extent[1]
	XS-37	5182	72.9	1 m Depth	166.1	1 m Depth
	XS-36	5058	27.0	Inundation Extent[1]	267.5	1 m Depth
	XS-35	4968	9.3	Inundation Extent[1]	313.6	1 m Depth
	XS-34	4890	61.8	Inundation Extent[1]	401.8	1 m Depth
	XS-33	4778	32.5	Inundation Extent[1]	356.2	Inundation Extent[1]
	XS-32	4663	40.3	1 m Depth	275.8	Inundation Extent[1]
	XS-31	4579	65.1	1 m Depth	225.2	1 m Depth
	XS-30	4515	104.9	Inundation Extent[1]	142.9	Main Channel
	XS-29	4496	99.0	Inundation Extent[1]	134.7	Inundation Extent[1]
	XS-28	4383	20.4	Main Channel	60.7	Main Channel
	XS-27	4293	25.4	Main Channel	44.6	1 m/s Velocity
	XS-26	3939	261.7	Main Channel	286.4	Inundation Extent[1]
	XS-25	3687	79.1	Main Channel	96.6	1 m/s Velocity
	XS-24	3554	125.4	1 m Depth	224.3	1 m Depth

Table H-1 Floodway Limits and Determination Criteria (Continued)

River	Cross Section Number	River Station (m)	Left		Right	
			Floodway Limit	Determining Criteria	Floodway Limit	Determining Criteria
Embarras River	XS-23	3422	56.1	Inundation Extent[1]	102.7	1 m Depth
	XS-22	3284	108.7	1 m Depth	126.9	1 m Depth
	XS-21	3265	108.4	1 m Depth	127.5	1 m Depth
	XS-20	3194	50.6	1 m Depth	76.4	1 m Depth
	XS-19	3044	84.8	Main Channel	106.8	Main Channel
	XS-18	2935	119.4	1 m Depth	138.8	Main Channel
	XS-17	2765	98.8	1 m Depth	131.7	Main Channel
	XS-16	2597	46.5	Inundation Extent[1]	68.1	1 m Depth
	XS-15	2415	85.4	Main Channel	109.0	1 m Depth
	XS-14	2252	106.2	1 m Depth	131.0	Main Channel
	XS-13	2100	107.7	1 m Depth	131.8	1 m Depth
	XS-12	1917	63.0	Inundation Extent[1]	89.6	Main Channel
	XS-11	1783	141.9	Main Channel	171.2	1 m Depth
	XS-10	1610	55.7	1 m Depth	180.2	1 m Depth
	XS-9	1463	164.2	1 m Depth	186.2	Inundation Extent[1]
	XS-8	1347	132.3	1 m Depth	152.0	Main Channel
	XS-7	1226	113.2	1 m Depth	142.9	1 m Depth
	XS-6	1054	92.4	Inundation Extent[1]	118.6	1 m Depth
Bryan Creek	XS-111	3352	13.9	1 m/s Velocity	22.7	1 m Depth
	XS-110	3222	20.9	1 m Depth	26.7	1 m Depth
	XS-109	3162	20.7	1 m/s Velocity	26.6	1 m/s Velocity
	XS-108	3044	22.9	Main Channel	30.5	1 m Depth
	XS-107	2870	35.4	1 m Depth	42.4	Main Channel
	XS-106	2707	25.6	1 m Depth	32.0	1 m Depth
	XS-105	2510	25.2	Main Channel	32.3	Main Channel
	XS-104	2329	36.6	1 m Depth	44.6	1 m Depth
	XS-103	2198	34.3	1 m/s Velocity	40.5	1 m/s Velocity
	XS-102	2013	29.0	Inundation Extent[1]	38.4	Main Channel
	XS-101	1811	24.6	Inundation Extent[1]	34.1	1 m/s Velocity
	XS-100	1653	44.7	1 m Depth	51.9	1 m Depth

Table H-1 Floodway Limits and Determination Criteria (Continued)

River	Cross Section Number	River Station (m)	Left		Right	
			Floodway Limit	Determining Criteria	Floodway Limit	Determining Criteria
Bryan Creek	XS-99	1470	15.6	Inundation Extent[1]	50.4	1 m Depth
	XS-98	1387	48.4	1 m Depth	81.7	1 m Depth
	XS-97	1319	59.8	Main Channel	67.0	Main Channel
	XS-96	1084	65.5	Main Channel	72.5	Inundation Extent[1]
	XS-95	968	16.2	Inundation Extent[1]	23.1	1 m/s Velocity
	XS-94	844	53.9	1 m/s Velocity	65.3	Inundation Extent[1]
	XS-93	740	53.3	Main Channel	66.9	1 m Depth
	XS-92	611	19.3	Inundation Extent[1]	82.1	1 m Depth
	XS-91	553	104.2	1 m Depth	136.0	1 m Depth
	XS-90	510	100.3	Main Channel	117.1	Inundation Extent[1]
	XS-89	408	60.6	1 m Depth	81.6	Main Channel
	XS-88	301	37.8	Inundation Extent[1]	52.6	1 m Depth
	XS-87	245	25.5	Inundation Extent[1]	72.8	Inundation Extent[1]
	XS-86	153	45.6	Inundation Extent[1]	124.0	Inundation Extent[1]
	XS-85	95	33.2	Inundation Extent[1]	135.1	Inundation Extent[1]
	XS-84	8	16.3	Inundation Extent[1]	109.7	Inundation Extent[1]

Notes: 1. No viable flood fringe.

Table H-2 Computed Design Flood Levels

River	Cross Section Number	River Station (m)	Design Flood Level (m)	River	Cross Section Number	River Station (m)	Design Flood Level (m)
Embarras River	XS-83	10796	1134.05	Embarras River	XS-53	6867	1105.07
	XS-82	10649	1133.38		XS-52	6856	1104.90
	XS-81	10474	1132.64		XS-51	6832	1104.69
	XS-80	10389	1132.21		XS-50	6738	1104.02
	XS-79	10178	1131.49		XS-49	6609	1103.38
	XS-78	9974	1130.49		XS-48	6557	1103.05
	XS-77	9887	1130.16		XS-47	6541	1102.93
	XS-76	9877	1130.02		XS-46	6487	1102.64
	XS-75	9834	1129.61		XS-45	6358	1101.72
	XS-74	9689	1128.81		XS-44	6225	1100.90
	XS-73	9500	1128.17		XS-43	6086	1099.93
	XS-72	9271	1126.65		XS-42	5928	1098.79
	XS-71	9113	1126.06		XS-41	5777	1097.87
	XS-70	9021	1125.62		XS-40	5647	1096.69
	XS-69	9005	1125.47		XS-39	5463	1095.56
	XS-68	8959	1125.21		XS-38	5331	1095.39
	XS-67	8864	1124.97		XS-37	5182	1095.35
	XS-66	8721	1124.14		XS-36	5058	1095.34
	XS-65	8669	1123.65		XS-35	4968	1095.34
	XS-64	8593	1123.17		XS-34	4890	1095.30
	XS-63	8350	1121.62		XS-33	4778	1095.27
	XS-62	8204	1120.61		XS-32	4663	1095.25
	XS-61	8007	1118.10		XS-31	4579	1095.22
	XS-60	7809	1115.09		XS-30	4515	1087.06
	XS-59	7639	1112.69		XS-29	4496	1086.93
	XS-58	7404	1109.41		XS-28	4383	1086.47
	XS-57	7254	1108.19		XS-27	4293	1085.94
	XS-56	7143	1107.32		XS-26	3939	1084.12
	XS-55	7036	1106.45		XS-25	3687	1082.02
	XS-54	6926	1105.51		XS-24	3554	1081.54

Table H-2 Computed Design Flood Levels (Continued)

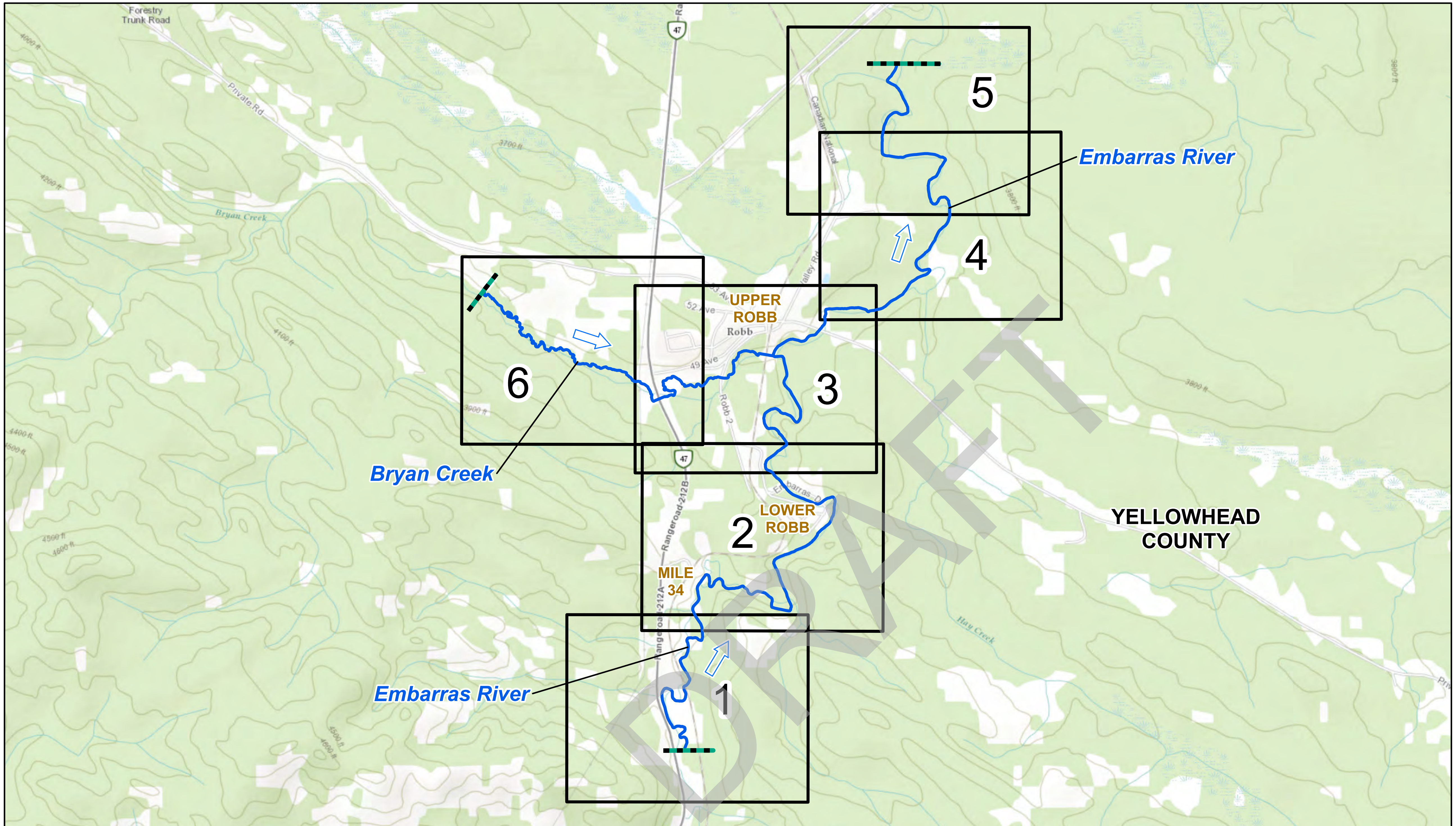
River	Cross Section Number	River Station (m)	Design Flood Level (m)	River	Cross Section Number	River Station (m)	Design Flood Level (m)
Embarras River	XS-23	3422	1081.12	Embarras River	XS-11	1783	1074.14
	XS-22	3284	1080.52		XS-10	1610	1073.64
	XS-21	3265	1080.22		XS-9	1463	1073.12
	XS-20	3194	1079.81		XS-8	1347	1072.50
	XS-19	3044	1079.04		XS-7	1226	1072.13
	XS-18	2935	1078.54		XS-6	1054	1071.62
	XS-17	2765	1078.06		XS-5	898	1071.11
	XS-16	2597	1077.44		XS-4	617	1069.70
	XS-15	2415	1076.67		XS-3	390	1068.32
	XS-14	2252	1076.04		XS-2	224	1067.67
	XS-13	2100	1075.46		XS-1	0	1066.73
	XS-12	1917	1074.79				
Bryan Creek	XS-111	3352	1123.00	Bryan Creek	XS-97	1319	1107.71
	XS-110	3222	1122.45		XS-96	1084	1105.59
	XS-109	3162	1121.85		XS-95	968	1104.43
	XS-108	3044	1121.17		XS-94	844	1102.86
	XS-107	2870	1120.20		XS-93	740	1102.33
	XS-106	2707	1119.40		XS-92	611	1102.26
	XS-105	2510	1118.30		XS-91	553	1102.25
	XS-104	2329	1117.26		XS-90	510	1098.58
	XS-103	2198	1116.21		XS-89	408	1098.06
	XS-102	2013	1114.65		XS-88	301	1097.98
	XS-101	1811	1112.87		XS-87	245	1097.97
	XS-100	1653	1112.10		XS-86	153	1097.97
	XS-99	1470	1111.89		XS-85	95	1097.96
	XS-98	1387	1111.83		XS-84	8	1095.31

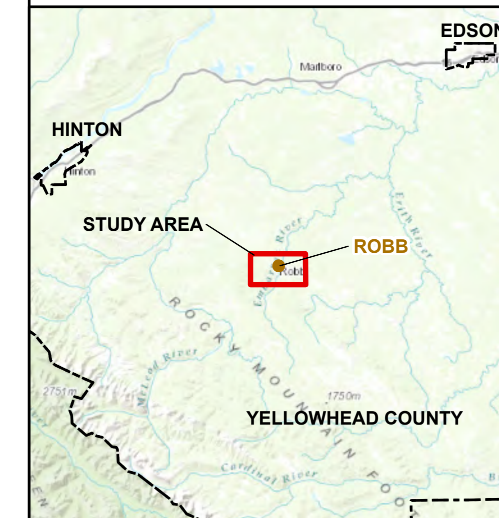
September 2025

APPENDIX I

FLOODWAY CRITERIA MAP

Robb Flood Study
Main Report





FLOW DIRECTION
STUDY LIMIT
STUDY REACH
MAP SHEET

Notes to Users:

1. Please refer to the accompanying **Robb Flood Study Report** for important information concerning these maps.
2. Within the flood inundation areas shown on this map, there may be isolated pockets of high ground. To determine whether or not a particular site is subject to flooding, reference should be made to the computed flood levels in conjunction with site-specific surveys where detailed definition is required.
3. Non-riverine and local sources of water have not been considered, and structures such as roads, railways, or barriers such as levees can restrict water flow and affect local flood levels. Channel obstruction, local stormwater inflow, groundwater seepage, or other land drainage can cause flood levels to exceed those indicated on the map. Lands adjacent to a flooded area may be subject to flooding from tributary streams not indicated on the maps.
4. The flood inundation area is shown above the line work for bridges and flood control structures that are below flood levels.

Definitions:

Flood Hazard Map - A flood hazard map is a specific type of flood map that identifies the area flooded for the 1:100 design flood, and divides that flood hazard area into floodway and flood fringe zones. Flood hazard maps can also show additional flood hazard information, including the incremental areas at risk for more severe floods like the 1:200 and 1:500 floods. Flood hazard maps are typically used for long-term flood hazard area management and land-use planning.
Design Flood - The design flood standard in Alberta is the 1:100 flood, which is a flood that has a 1% chance of being equaled or exceeded in any given year. The design flood is typically based on the 1:100 open water flood, but it can also reflect 1:100 ice jam flood levels or be based on a historical flood event. Different sized floods have different chances of occurring – for example, a 1:200 flood has a 0.5% chance of occurring in any given year and a 1:500 flood has a 0.2% chance of occurring in any given year – but only the 1:100 design flood is used to define the floodway and flood fringe zones on flood hazard maps.
Floodway - When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 1:100 design flood. When a flood hazard map is updated, the floodway will not get larger in most circumstances to maintain long-term regulatory certainty, even if the flood hazard area gets larger or design flood levels get higher.
Flood Fringe - The flood fringe is the area outside of the floodway that is flooded or could be flooded during the 1:100 design flood. The flood fringe typically represents areas with

Definitions (continued):

shallower, slower, and less destructive flooding, but it may also include "high hazard flood fringe" areas. Areas at risk of flooding behind flood berms may also be mapped as "protected flood fringe" areas.
High Hazard Flood Fringe - The high hazard flood fringe identifies areas within the flood fringe with deeper or faster moving water than the rest of the flood fringe. High hazard flood fringe areas are likely to be most significant for flood maps that are being updated, but they may also be included in new flood maps.
Protected Flood Fringe - The protected flood fringe identifies areas that could be flooded if dedicated flood berms fail or do not work as designed during the 1:100 design flood, even if they are not overtopped. Protected flood fringe areas are part of the flood fringe and do not differentiate between areas with deeper or faster moving water and shallower or slower moving water.

Data Sources and References:

1. Aerial Imagery Source: From ESRI World Imagery, ESRI, Maxar, Earthstar Geographics, and the GIS user community, Imagery dated on 09 AUG 2024
2. Flood extent mapping is based on a digital terrain model derived from 2024 LiDAR data collected by Airborne Imaging Inc. for Alberta Environment and Protected Areas and 2024 bathymetric and topographic survey data collected by Northwest Hydraulic Consultants Ltd.
3. Base data from Hamlet of Robb, Natural Resources Canada, Alberta Environment and Protected Areas, and Altalis.

SCALE - 1:30,000
0 200 400 600 m
N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

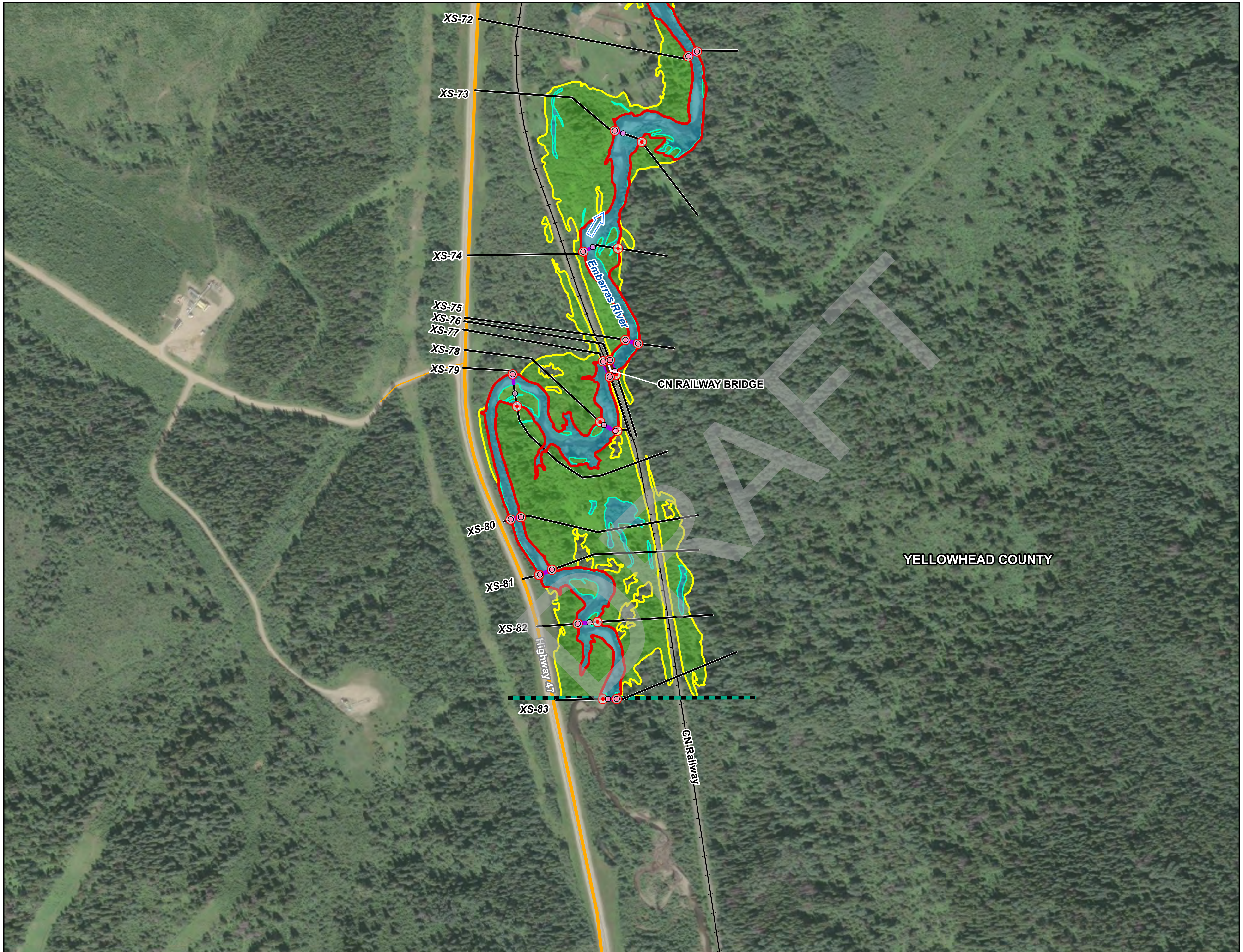
Job Number	Date
1009252	24-JUL-2025

ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

INDEX MAP

SHEET 2 ↑



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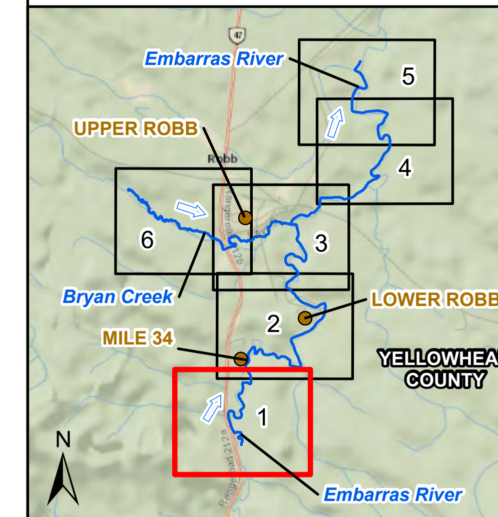

- MAJOR HIGHWAY
- LOCAL ROAD
- RAILWAY
- BRIDGE
- CULVERT
- STUDY LIMIT
- CROSS SECTION
- FLOW DIRECTION
- BANK STATION
- VELOCITY ≥ 1 m/s
- 1 m DEPTH CONTOUR
- DEPTH ≥ 1 m
- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- PROPOSED FLOODWAY LIMIT
- PROPOSED FLOODWAY BOUNDARY

DISCHARGE

EMBARRAS RIVER ABOVE BRYAN CREEK = 70.0 m^3/s

SCALE - 1:5,000

0 50 100 M

N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

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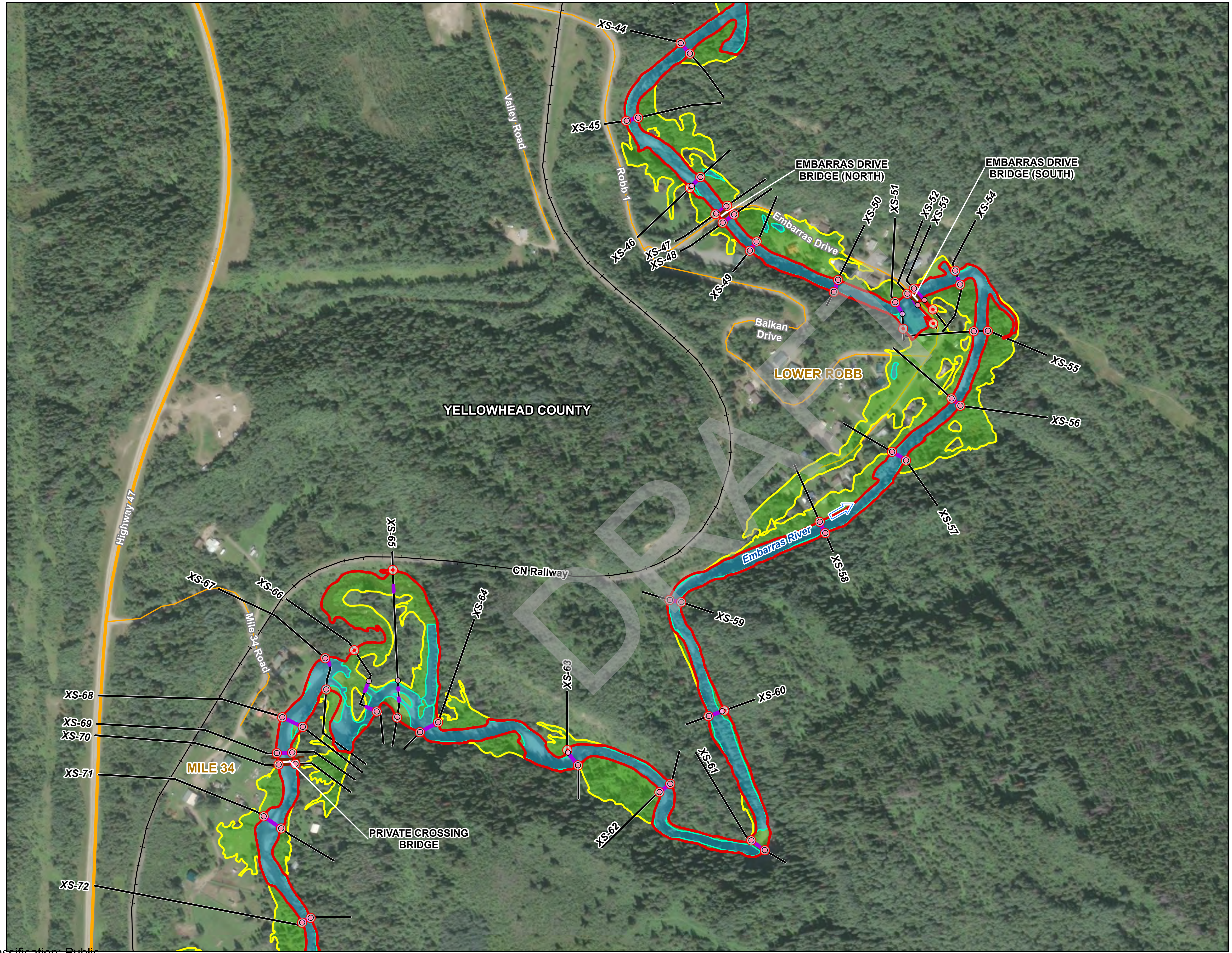
ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

JY, P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOODWAY CRITERIA .aprx

SHEET 3 ↑



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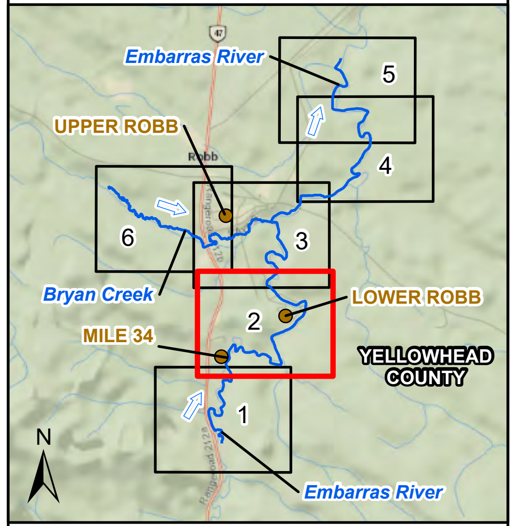

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- RAILWAY
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- STUDY LIMIT
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- PROPOSED FLOODWAY LIMIT
- PROPOSED FLOODWAY BOUNDARY

DISCHARGE
EMBARRAS RIVER ABOVE BRYAN CREEK = 70.0 m^3/s

SCALE - 1:5,000
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N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

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ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 2 OF 6

SHEET 4 ↑

SHEET 2 ↓

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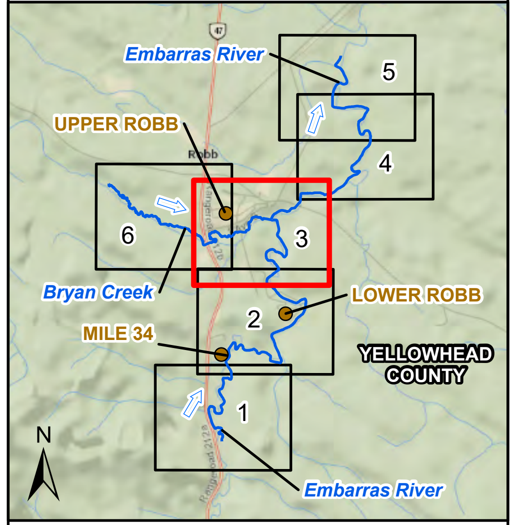

- MAJOR HIGHWAY
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- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- PROPOSED FLOODWAY LIMIT
- PROPOSED FLOODWAY BOUNDARY

DISCHARGE
EMBARRAS RIVER ABOVE BRYAN CREEK = 70.0 m^3/s
EMBARRAS RIVER BELOW BRYAN CREEK = 90.0 m^3/s
BRYAN CREEK = 19.2 m^3/s

SCALE - 1:5,000
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Coordinate System: NAD 1983 CSRS 3TM 117;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

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ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 3 OF 6

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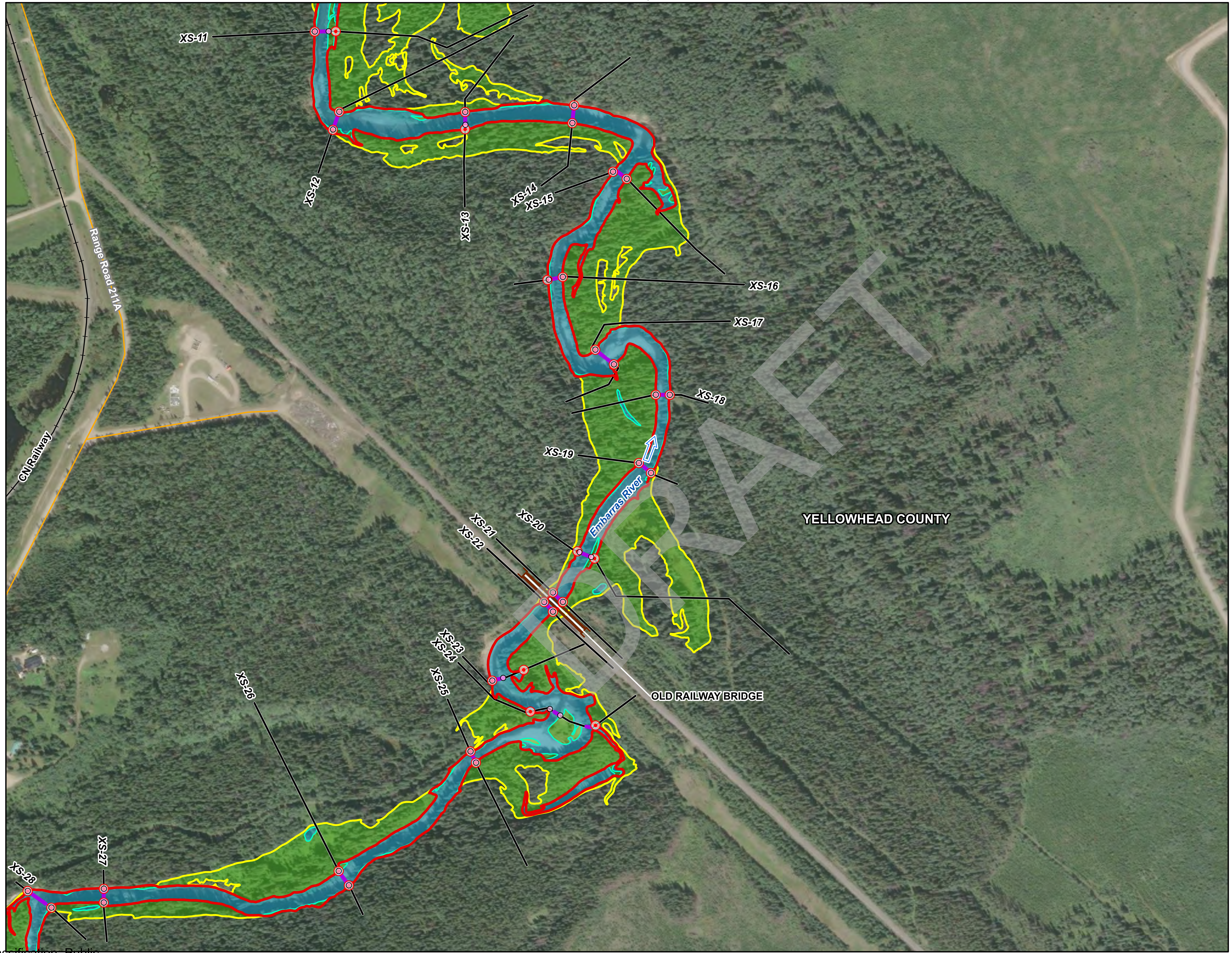
SHEET 5 ↑



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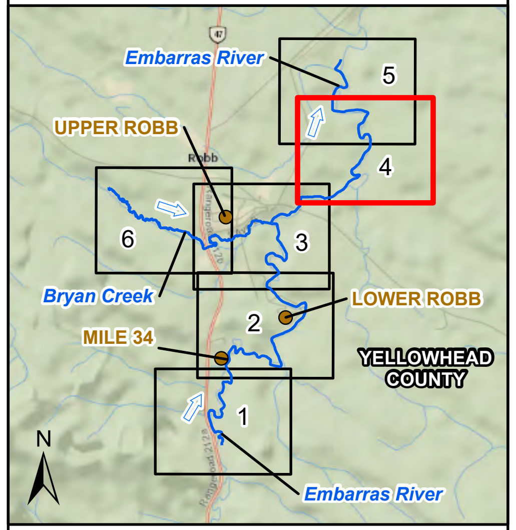

MAJOR HIGHWAY
LOCAL ROAD
RAILWAY
BRIDGE
CULVERT
STUDY LIMIT
CROSS SECTION
FLOW DIRECTION
BANK STATION
VELOCITY ≥ 1 m/s
1 m DEPTH CONTOUR
DEPTH ≥ 1 m
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
PROPOSED FLOODWAY LIMIT
PROPOSED FLOODWAY BOUNDARY

DISCHARGE
EMBARRAS RIVER BELOW BRYAN CREEK = 90.0 m^3/s

SCALE - 1:5,000
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N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	10-AUG-2025

ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 4 OF 6

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Classification: Public

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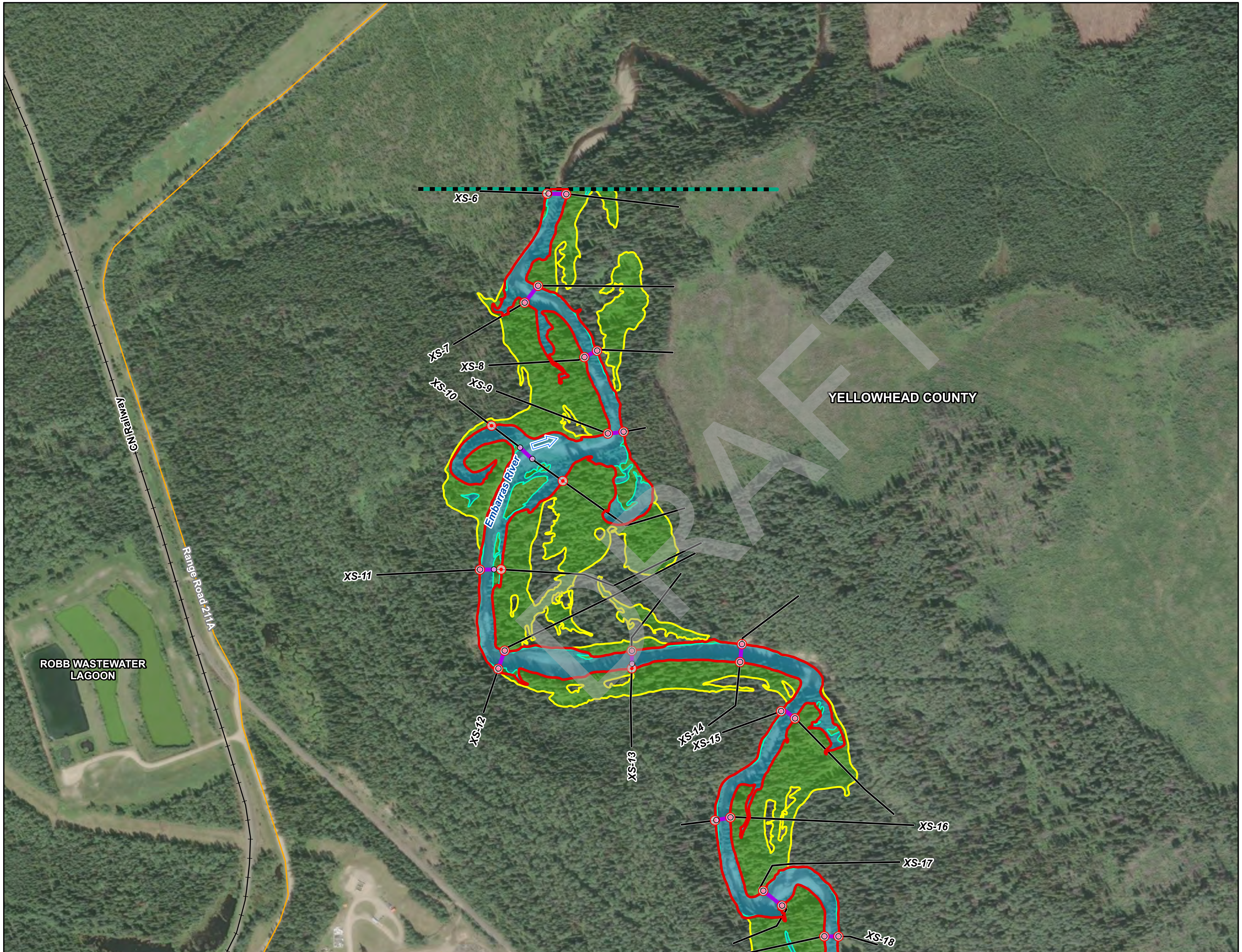

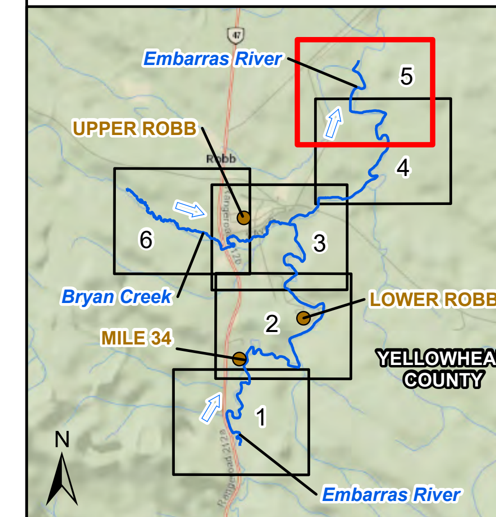

- MAJOR HIGHWAY
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- RAILWAY
- BRIDGE
- CULVERT
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- DEPTH ≥ 1 m
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- PROPOSED FLOODWAY LIMIT
- PROPOSED FLOODWAY BOUNDARY

DISCHARGE
EMBARRAS RIVER BELOW BRYAN CREEK = 90.0 m^3/s

SCALE - 1:5,000
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N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	10-AUG-2025

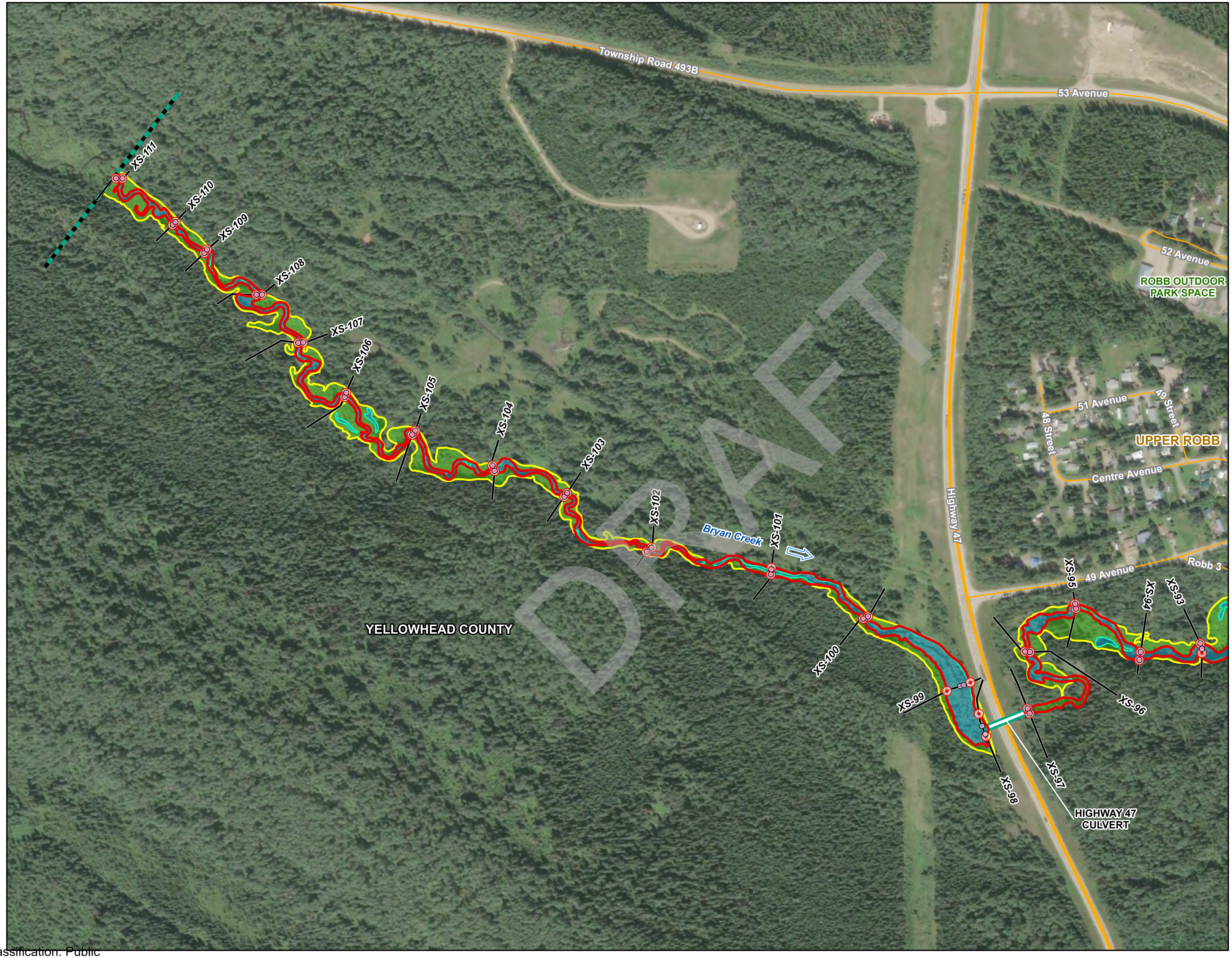
ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 5 OF 6

Classification: Public

SHEET 4 ↓



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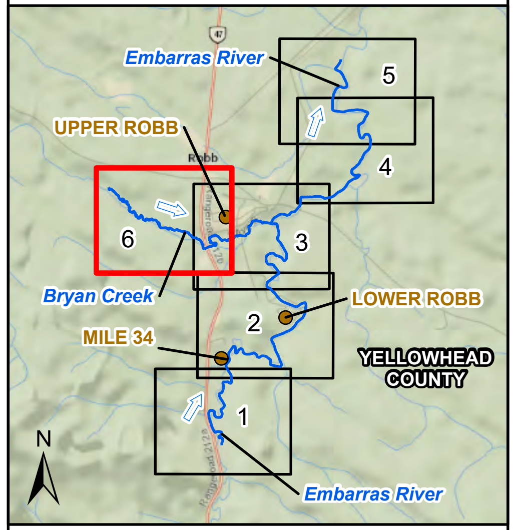

MAJOR HIGHWAY
LOCAL ROAD
RAILWAY
BRIDGE
CULVERT
STUDY LIMIT
CROSS SECTION
FLOW DIRECTION
BANK STATION
VELOCITY ≥ 1 m/s
1 m DEPTH CONTOUR
DEPTH ≥ 1 m
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
PROPOSED FLOODWAY LIMIT
PROPOSED FLOODWAY BOUNDARY

DISCHARGE
BRYAN CREEK = 19.2 m^3/s

SCALE - 1:5,000
0 50 100 M
N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
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Job Number	Date
1009252	10-AUG-2025

ROBB FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 6 OF 6

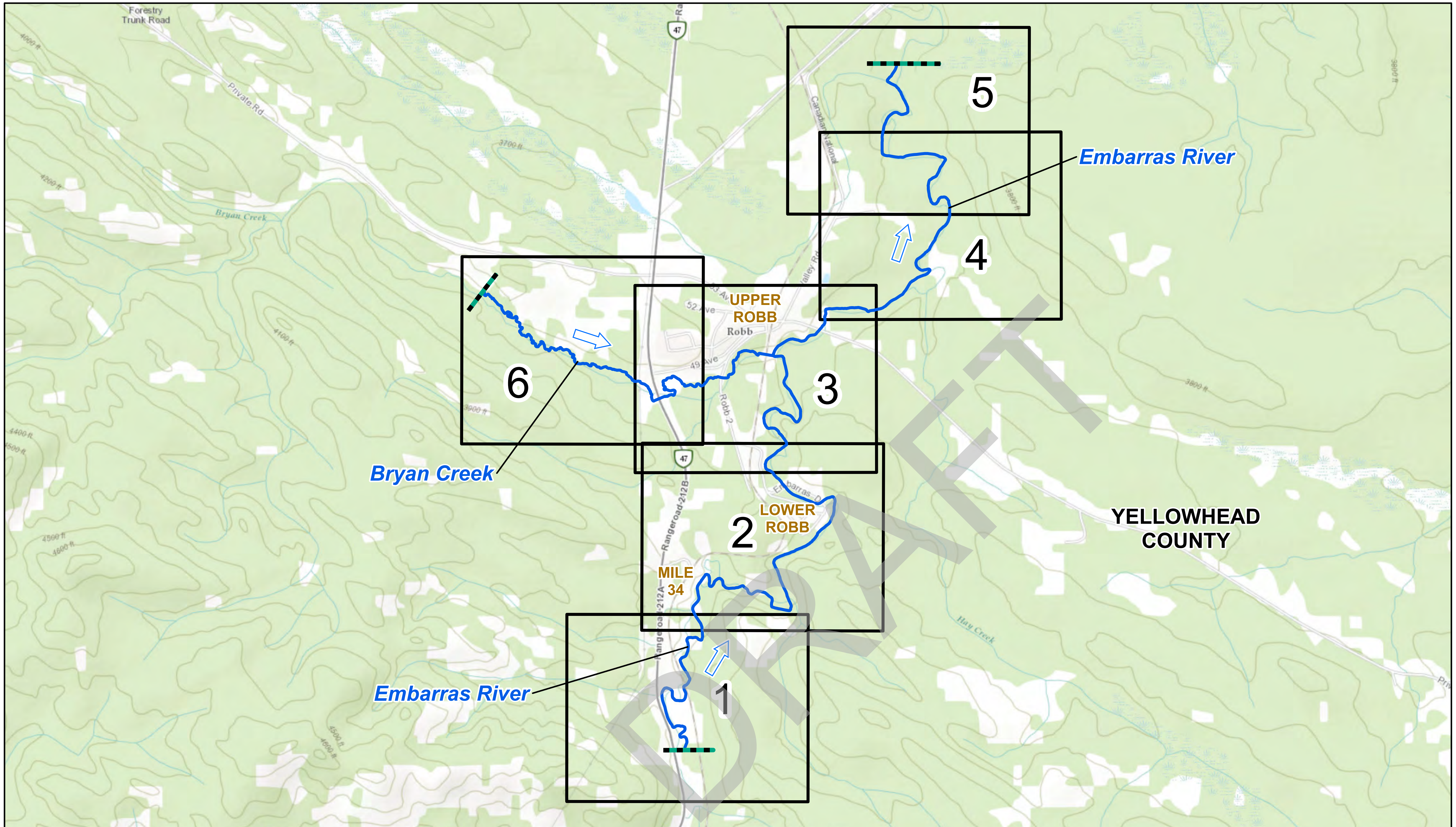
JY, P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOODWAY CRITERIA.aprx

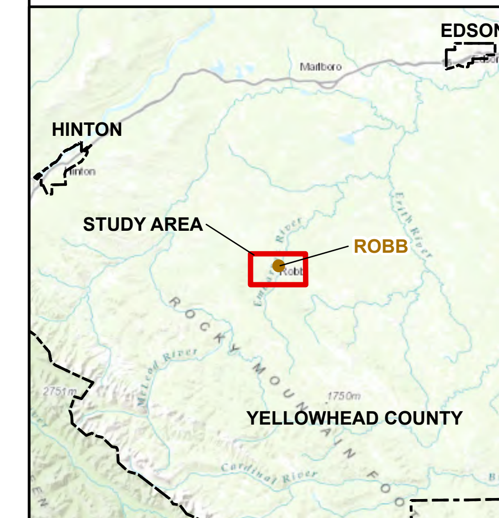
September 2025

APPENDIX J

FLOOD HAZARD MAP

Robb Flood Study
Main Report





FLOW DIRECTION
STUDY LIMIT
STUDY REACH
MAP SHEET

SCALE - 1:30,000
0 200 400 600 m

N

Coordinate System: NAD 1983 CSRS 3TM 117; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer MMM	GIS JY	Reviewer MSN/RBA
Job Number 1009252	Date 24-JUL-2025	

ROBB FLOOD STUDY

FLOOD HAZARD MAP

INDEX MAP

Notes to Users:

1. Please refer to the accompanying **Robb Flood Study Report** for important information concerning these maps.
2. Within the flood inundation areas shown on this map, there may be isolated pockets of high ground. To determine whether or not a particular site is subject to flooding, reference should be made to the computed flood levels in conjunction with site-specific surveys where detailed definition is required.
3. Non-riverine and local sources of water have not been considered, and structures such as roads, railways, or barriers such as levees can restrict water flow and affect local flood levels. Channel obstruction, local stormwater inflow, groundwater seepage, or other land drainage can cause flood levels to exceed those indicated on the map. Lands adjacent to a flooded area may be subject to flooding from tributary streams not indicated on the maps.
4. The flood inundation area is shown above the line work for bridges and flood control structures that are below flood levels.

Definitions:

Flood Hazard Map - A flood hazard map is a specific type of flood map that identifies the area flooded for the 1:100 design flood, and divides that flood hazard area into floodway and flood fringe zones. Flood hazard maps can also show additional flood hazard information, including the incremental areas at risk for more severe floods like the 1:200 and 1:500 floods. Flood hazard maps are typically used for long-term flood hazard area management and land-use planning.

Design Flood - The design flood standard in Alberta is the 1:100 flood, which is a flood that has a 1% chance of being equaled or exceeded in any given year. The design flood is typically based on the 1:100 open water flood, but it can also reflect 1:100 ice jam flood levels or be based on a historical flood event. Different sized floods have different chances of occurring – for example, a 1:200 flood has a 0.5% chance of occurring in any given year and a 1:500 flood has a 0.2% chance of occurring in any given year – but only the 1:100 design flood is used to define the floodway and flood fringe zones on flood hazard maps.

Floodway - When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 1:100 design flood. When a flood hazard map is updated, the floodway will not get larger in most circumstances to maintain long-term regulatory certainty, even if the flood hazard area gets larger or design flood levels get higher.

Flood Fringe - The flood fringe is the area outside of the floodway that is flooded or could be flooded during the 1:100 design flood. The flood fringe typically represents areas with shallower, slower, and less destructive flooding, but it may also include "high hazard flood fringe" areas. Areas at risk of flooding behind flood berms may also be mapped as "protected flood fringe" areas.

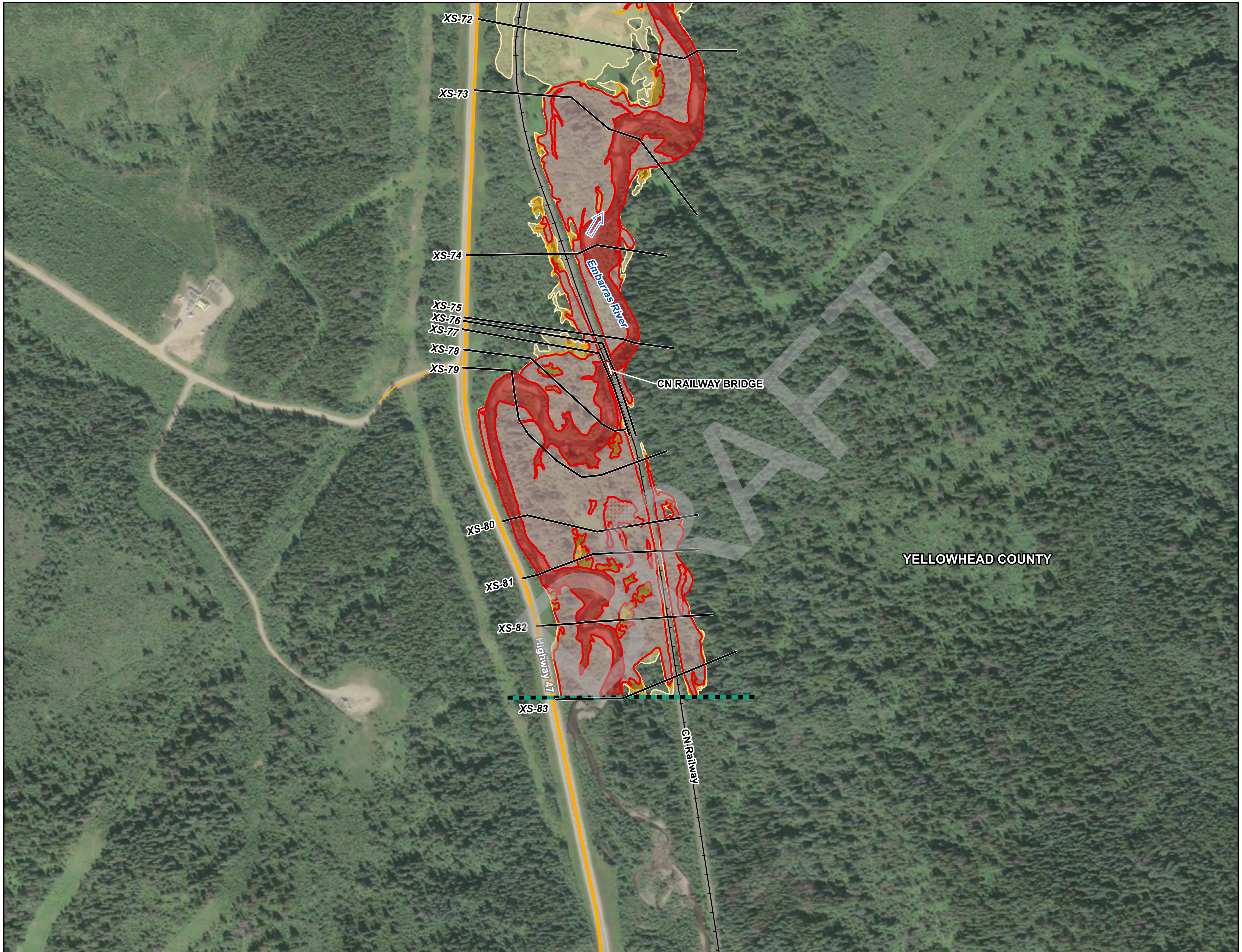
High Hazard Flood Fringe - The high hazard flood fringe identifies areas within the flood fringe with deeper or faster moving water than the rest of the flood fringe. High hazard flood fringe areas are likely to be most significant for flood maps that are being updated, but they may also be included in new flood maps.

Protected Flood Fringe - The protected flood fringe identifies areas that could be flooded if dedicated flood berms fail or do not work as designed during the 1:100 design flood, even if they are not overtopped. Protected flood fringe areas are part of the flood fringe and do not differentiate between areas with deeper or faster moving water and shallower or slower moving water.

Data Sources and References:

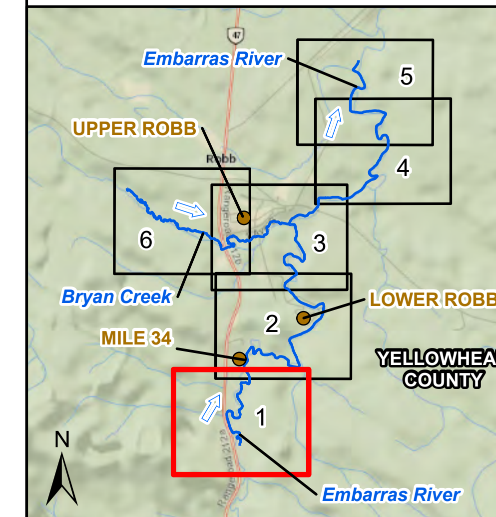
1. Aerial Imagery Source: From ESRI World Imagery, ESRI, Maxar, Earthstar Geographics, and the GIS user community, Imagery dated on 09 AUG 2024
2. Flood extent mapping is based on a digital terrain model derived from 2024 LiDAR data collected by Airborne Imaging Inc. for Alberta Environment and Protected Areas and 2024 bathymetric and topographic survey data collected by Northwest Hydraulic Consultants Ltd.
3. Base data from Hamlet of Robb, Natural Resources Canada, Alberta Environment and Protected Areas, and Altalis.

SHEET 2 ↑



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- RAILWAY
- BRIDGE
- CULVERT
- STUDY LIMIT
- CROSS SECTION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

DISCHARGE
EMBARRAS RIVER ABOVE BRYAN CREEK = 70.0 m^3/s

SCALE - 1:5,000
0 50 100 M
N

Coordinate System: NAD 1983 CSRS 3TM 117;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	MSN/RBA

Job Number	Date
1009252	10-AUG-2025

ROBB FLOOD STUDY

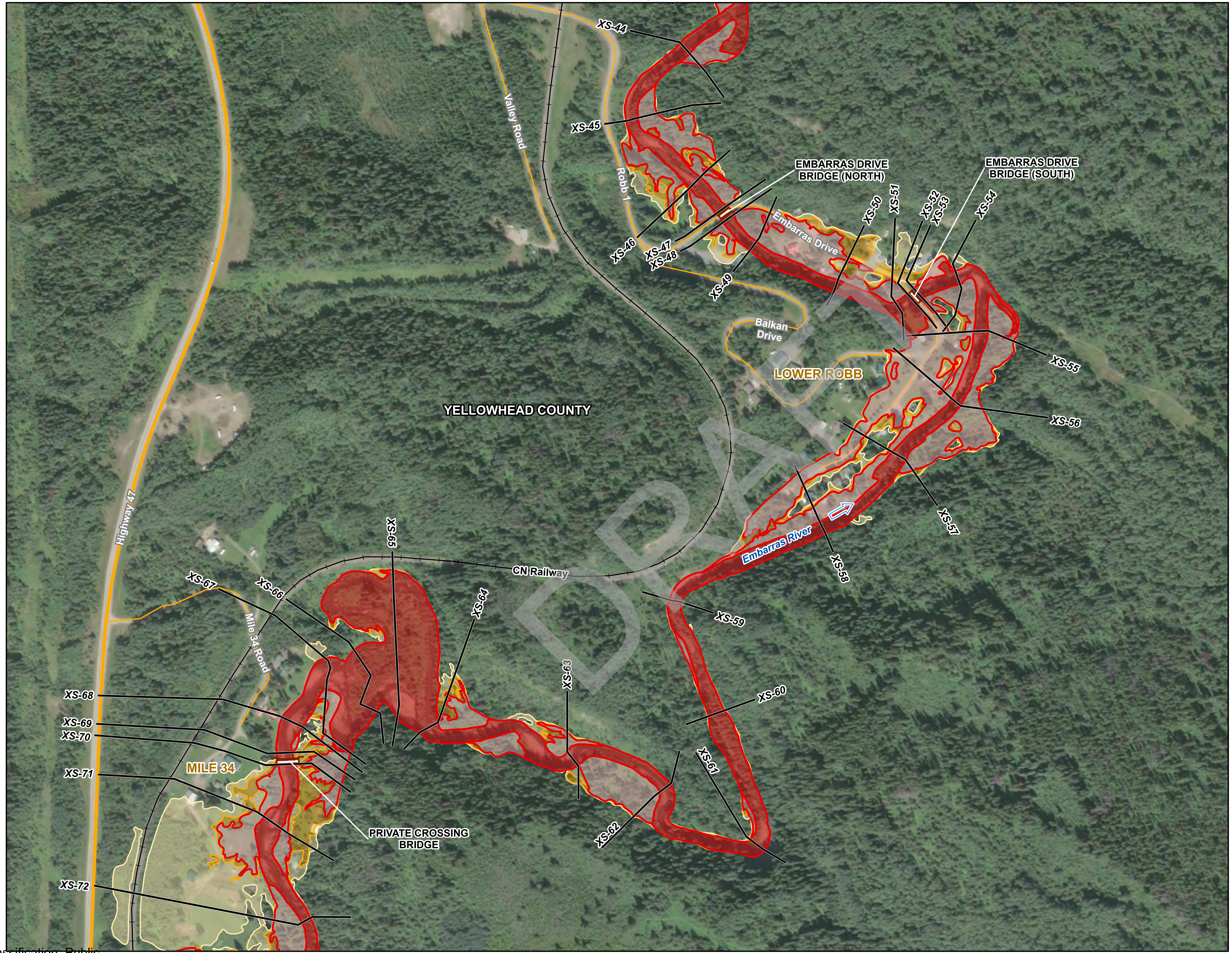
FLOOD HAZARD MAP

SHEET 1 OF 6

JY, P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOOD HAZARD.aprx

Classification: Public

SHEET 3 ↑

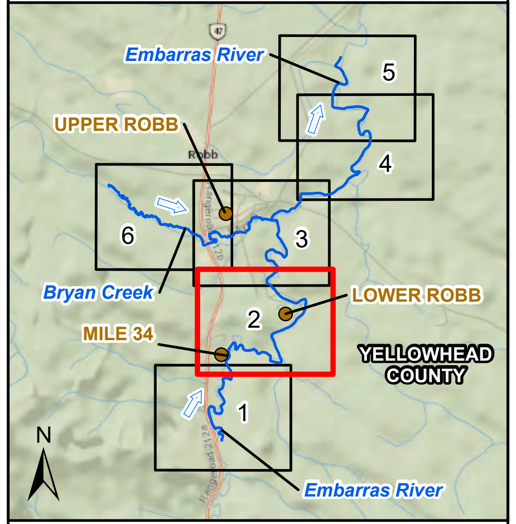


SHEET 1 ↓

Classification: Public

Alberta Canada

nhc



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DISCHARGE
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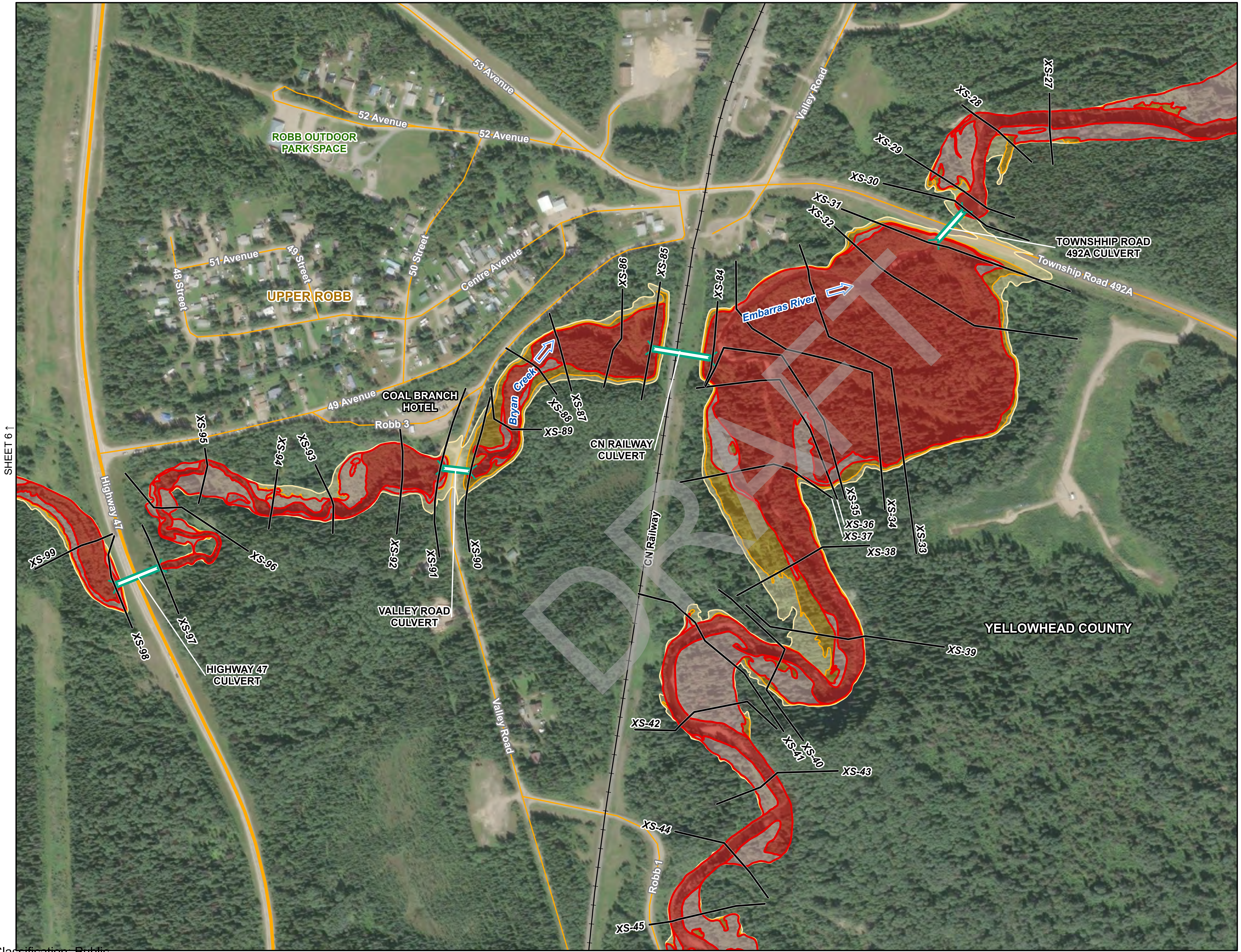
1009252	10-AUG-2025

ROBB FLOOD STUDY

FLOOD HAZARD MAP

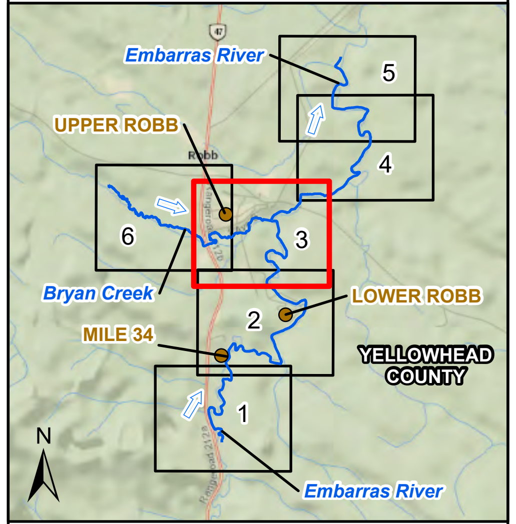
SHEET 2 OF 6

JY: P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOOD HAZARD.aprx



Alberta Canada

nhc



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- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

DISCHARGE
EMBARRAS RIVER ABOVE BRYAN CREEK = 70.0 m^3/s
EMBARRAS RIVER BELOW BRYAN CREEK = 90.0 m^3/s
BRYAN CREEK = 19.2 m^3/s

SCALE - 1:5,000
0 50 100 M
N

Coordinate System: NAD 1983 CSRS 3TM 117;
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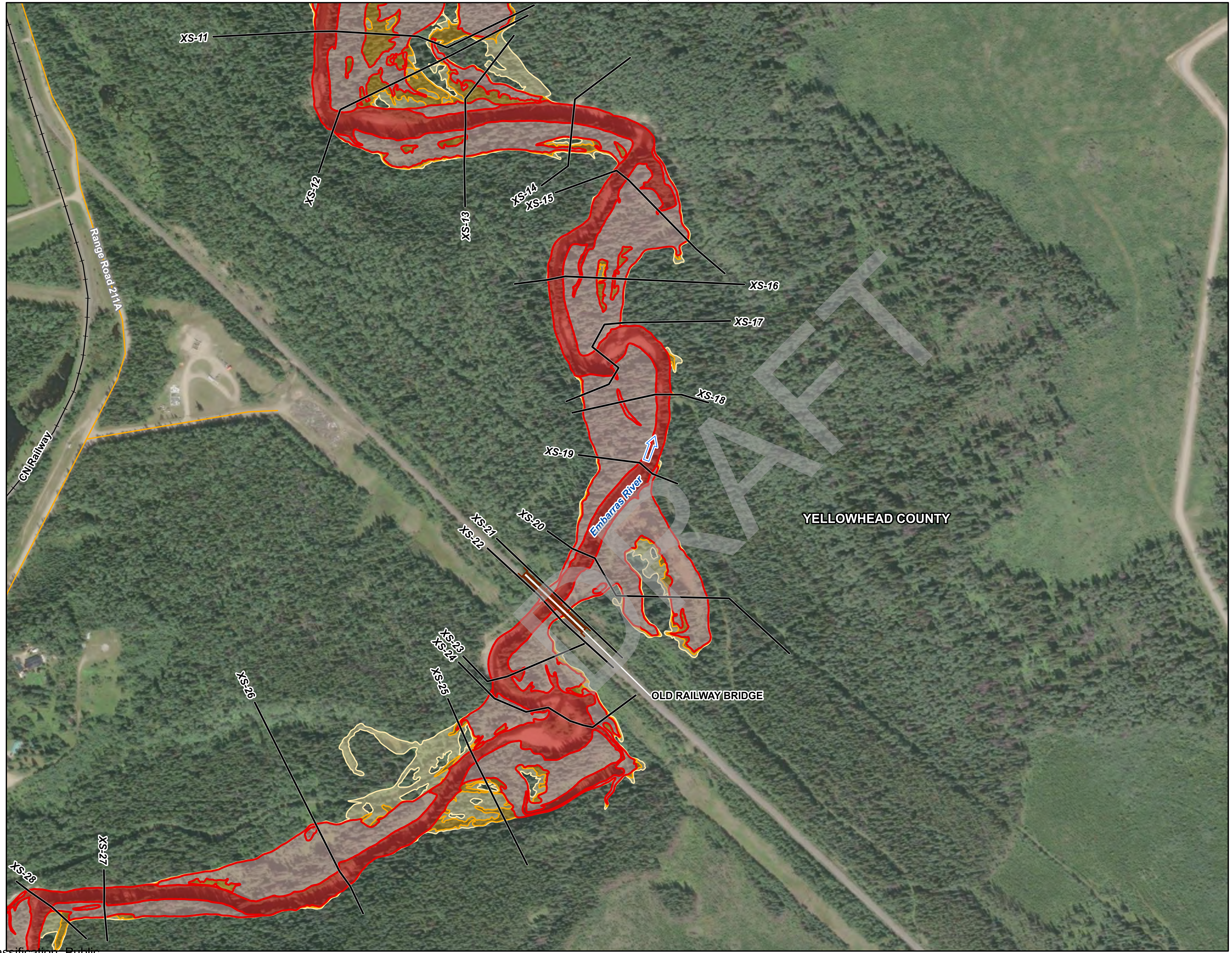
ROBB FLOOD STUDY

FLOOD HAZARD MAP

JY, P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOOD HAZARD.aprx

SHEET 5 ↑



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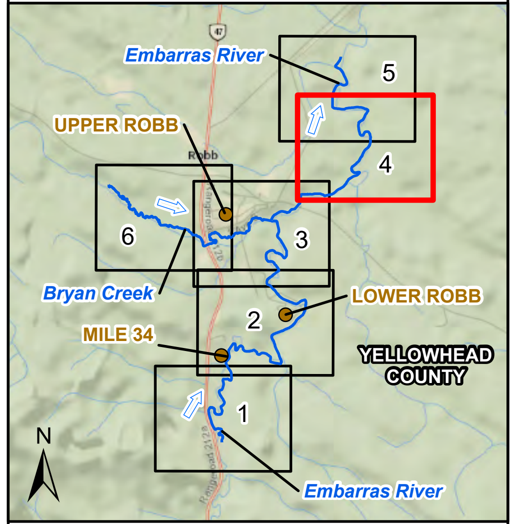

MAJOR HIGHWAY
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CROSS SECTION
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FLOODWAY
FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

DISCHARGE
EMBARRAS RIVER BELOW BRYAN CREEK = 90.0 m^3/s

SCALE - 1:5,000
0 50 100 M
N

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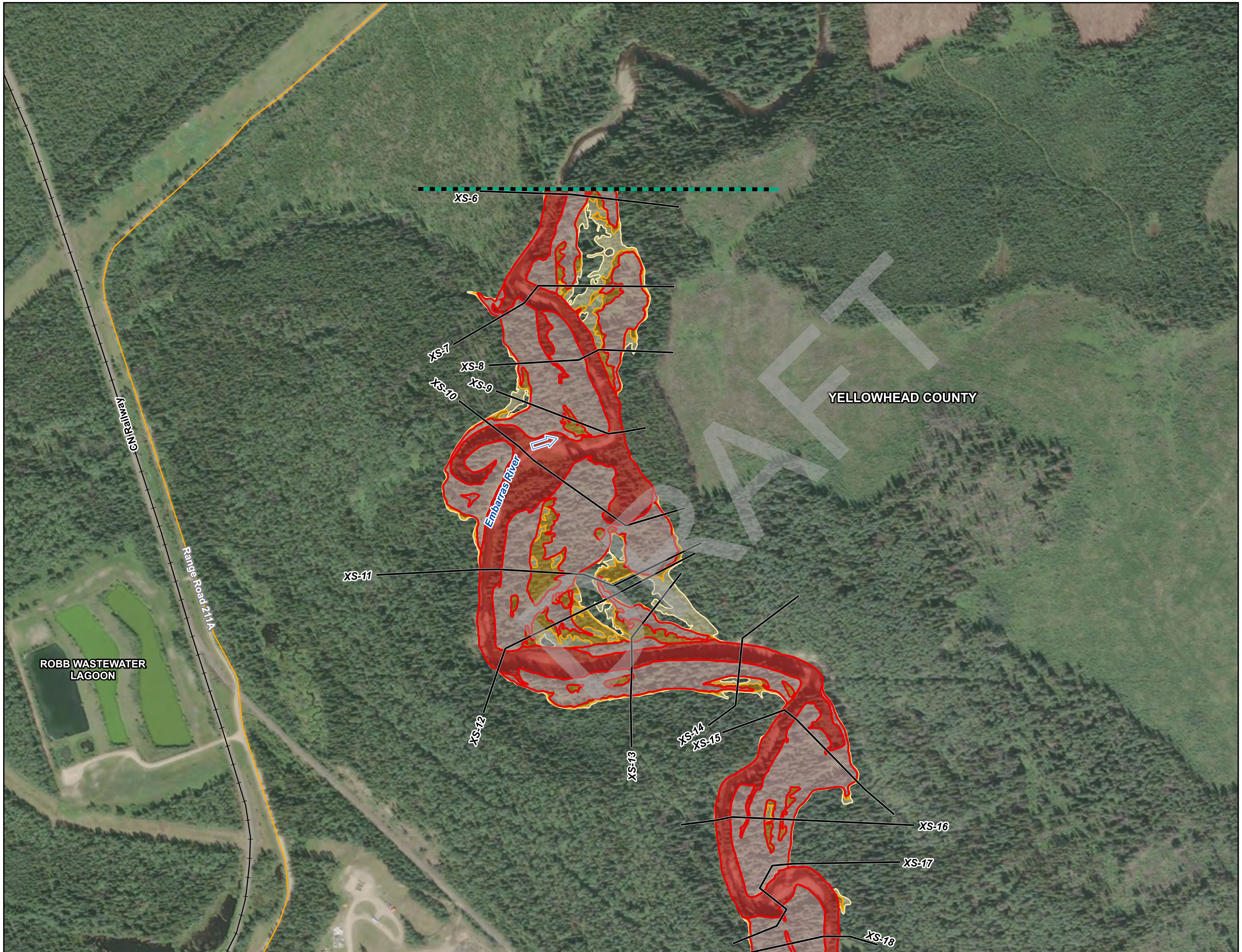
1009252	10-AUG-2025

ROBB FLOOD STUDY

FLOOD HAZARD MAP

SHEET 4 OF 6

JY, P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOOD HAZARD.aprx

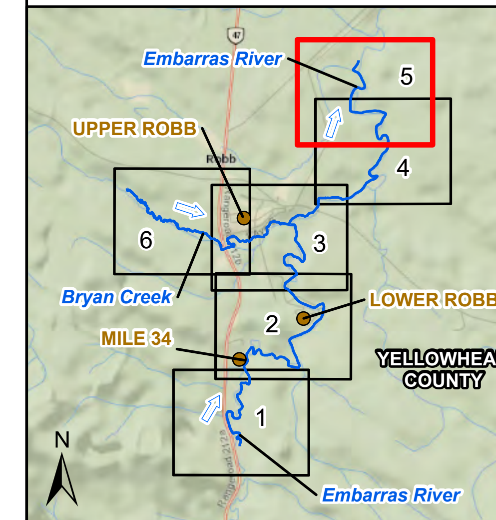


Classification: Public

SHEET 4 ↓

Alberta Canada

nhc



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DISCHARGE
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ROBB FLOOD STUDY

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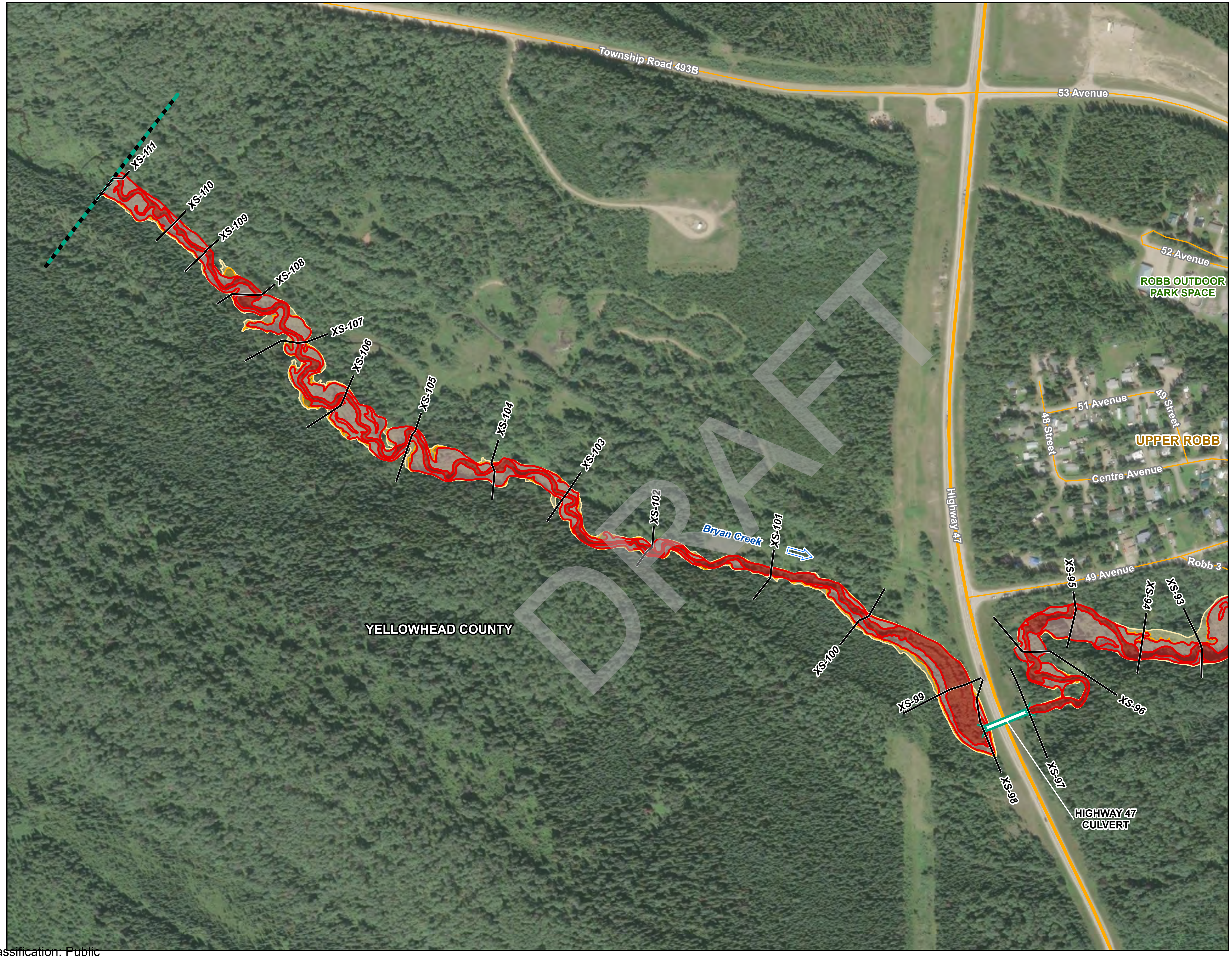

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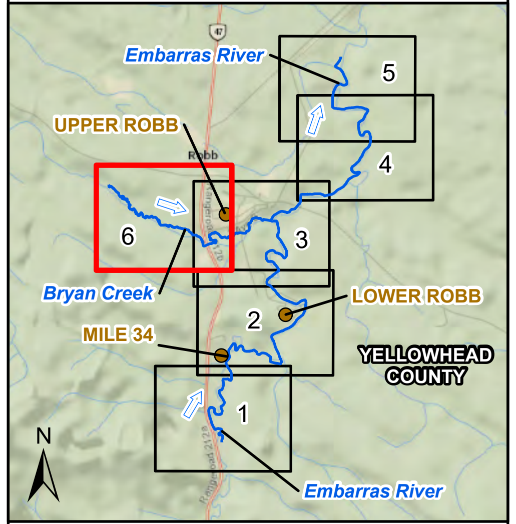
Alberta Canada

nhc



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DISCHARGE
BRYAN CREEK = 19.2 m^3/s

SCALE - 1:5,000
0 50 100 M
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ROBB FLOOD STUDY

FLOOD HAZARD MAP

SHEET 6 OF 6

JY, P:_Projects (Active)\1009252 Robb Flood Study\90_GIS\FLOOD HAZARD\ROBB FS FLOOD HAZARD.aprx