

Garden River Flood Study

Main Report

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EXECUTIVE SUMMARY

The Garden River Flood Study was initiated by Alberta Environment and Protected Areas (EPA) to identify and assess flood hazards along the Peace River and Garden Creek through Mackenzie County, Improvement District No. 24, and the Little Red River Cree Nation community of Garden River, which is located within Wood Buffalo National Park. This study is being undertaken as part of the Flood Hazard Identification Program (FHIP) with the intent of enhancing public safety and reducing future flood damages within the Province of Alberta.

The Garden River Flood Study provides assessment and identification of flood hazards under both open water and ice jam conditions. The study comprises eight major components: Survey and Base Data Collection, Open Water Hydrology Assessment, Open Water Hydraulic Modelling, Open Water Flood Inundation Mapping, Ice Jam Flood Assessment and Modelling, Ice Jam Flood Inundation Mapping, Design Flood Hazard Identification and Mapping, and Climate Change Impacts. This report summarizes the work of all eight components.

Open water flood frequency estimates were developed for the Peace River and Garden Creek for the 1:2, 1:5, 1:10, 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, 1:500, 1:750, and 1:1000 open water floods. While the developed ice jam flood frequency estimates were limited to the Peace River only for the 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, and 1:500 ice jam floods.

The main survey program was completed between 1 and 10 October 2024, and 26 May and 1 June 2025. The objective of the survey program was to survey channel cross sections in the study area to support the development of hydraulic models. 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.

A coupled 1D/2D hydraulic model was developed to compute flood levels in the study area for the various open water flood scenarios. The open water model was then enhanced to create an ice jam model to calculate the ice jam thickness and water surface profiles in the Peace River study area. The computed flood levels from each model 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 for both open water and ice jam conditions. A separate series of maps (denoted as map libraries) were created each for the open water and ice jam flood conditions. These libraries are intended primarily for stakeholders to use in emergency response planning and preparation.

The open water and ice jam floodway criteria maps and design flood hazard maps are key deliverables for this project and are provided as appendices to this report. Flood hazard identification involves defining the flood hazard area, which is comprised of floodway and flood fringe zones. Areas of deeper or faster moving water outside of the floodway (within the flood fringe) are identified as high hazard flood fringe areas. The design flood hazard map depicts the floodway and flood fringe based on the information resulting from the floodway criteria map.

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The methods summarized in this report follow the provincial FHIP Flood Study Technical Guidelines (June 2022), incorporating technical changes implemented in 2021 regarding how floodways are mapped in Alberta.

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1 INTRODUCTION

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 approximately 34 km of the Peace River and 19 km of Garden Creek through Mackenzie County, Improvement District No. 24, and the Little Red River Cree Nation community of Garden River, which is located within Wood Buffalo National Park. This study was facilitated under the Province's Flood Hazard Identification Program (FHIP) with the intent to enhance public safety and reduce future flood damages in Alberta. Results from this study are also intended to inform local land use planning decisions, flood mitigation projects, and emergency response planning.

This is the first flood study for these reaches. It provides assessment and identification of flood hazards under open water and ice jam conditions.

The study is comprised of the following eight study components:

1. Survey and Base Data Collection
2. Open Water Hydrology Assessment
3. Open Water Hydraulic Modelling
4. Open Water Flood Inundation Mapping
5. Ice Jam Flood Assessment and Modelling
6. Ice Jam Flood Inundation Mapping
7. Design Flood Hazard Identification and Mapping
8. Climate Change Impacts

The open water flood hydrology assessment was completed in the early stages of the project and is reproduced in this report as **Appendix A**. All other study components are summarized within the main body of this report.

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1.2 Study Objectives

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

- River cross section surveys
- Hydraulic structure data collection
- Survey and digital terrain model (DTM) data integration
- Open water and ice jam flood history documentation
- Open water hydrology assessment to provide open water flood frequency estimates
- Development of a calibrated open water hydraulic model and simulation of flood levels over a range of return periods
- Ice jam flood assessment to provide ice jam flood frequency estimates
- Enhancement of the open water hydraulic model to calculate ice-affected flood levels over a range of return periods
- Sensitivity analysis of simulated flood levels to variation in key modelling parameters (open water and ice-affected conditions)
- Production of open water and ice jam flood inundation maps for selected return periods
- Production of both open water and ice jam floodway criteria maps to support creation of design flood hazard maps for the selected design flood condition

1.3 Study Area

Figure 1 depicts the study area illustrating the extent of the Peace River and Garden Creek and boundaries of the mapping domain, which includes:

- A 47 km long reach of the Peace River extending from its west (upstream) boundary at 10-24-111-W5M to its east (downstream) boundary at 13-4-112-W4M.
- A 20 km long of Garden Creek extending upstream from its confluence with the Peace River at Garden River.

Modelling extended upstream and downstream of the mapping domain to limit the potential effects of model boundary conditions on the accuracy of results within the mapping domain.

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2 SURVEY AND BASE DATA COLLECTION

This section details the survey procedure and methodology, including the coordinate system and datum. It summarizes the control network points and discusses survey accuracy. Additionally, it describes the collected project base data, such as DTM, aerial imagery, surveyed cross sections, hydraulic structures, site photographs, and other base mapping features.

2.1 Digital Terrain Model

Fully processed and non-hydro-flattened, 0.5 m resolution, bare earth DTM and hill shade raster products were provided by EPA. The LiDAR data were acquired on 27 May 2024 and 13 June 2024 by Airborne Imaging. The horizontal spatial reference system is 3TM 114, NAD83 (CSRS), epoch 2002. The vertical datum is CGVD28. The LiDAR derived DTM was verified by EPA to meet or exceed a vertical accuracy of ±15 cm at 95%, on hard, flat, open (non-vegetated) surfaces, using independently collected survey data. A comparison between the survey data elevations and DTM elevation is provided in **Section 2.7**.

2.2 Aerial Imagery

Aerial imagery was not collected specifically for this project. EPA provided SPOT satellite imagery (RGB, 1.5 m resolution) of the study area collected 26 May 2023 and 21 June 2023. The imagery was used as the image background for all flood mapping products in addition to being used as visual reference to align various geometry features used to construct the hydraulic model.

2.3 Survey Procedures and Methodology

The survey program was completed between 1 and 10 October 2024, and 26 May and 1 June 2025. The objective of the survey program was to survey channel cross sections in the study area to support development of a hydraulic model. Before commencement of the work, a survey plan was submitted to and approved by EPA. A site visit was conducted on 2 October 2024 to inspect the study area and assess the overall conditions of the channel and floodplain.

Ground positioning for the survey was measured using Global Navigation Satellite Systems (GNSS) and Trimble R10 and R12 Real-Time Kinematic (RTK) GNSS receivers. In addition, the bathymetric surveys were performed in areas deeper than 0.3 metres using a Cee Echo single beam echo sounder mounted on a jet boat to measure water depth under the transducer. The position and height of the transducer were recorded with the RTK GNSS receiver mounted directly above it and paired using the Hypack software package for hydrographic surveying. Riverbed elevations were derived by subtracting sounding depths from transducer elevations. In shallower, wadable areas, elevations were directly measured with the RTK GNSS receiver

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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 for the survey can provide an accuracy of ±0.02 m under optimal operating conditions when the receiver is mounted to a tripod with a clear view of the sky and sufficient satellites to accurately establish the receiver position. Additional errors may be introduced when the receiver is off level, obstructed by nearby trees or vegetation, or the receiver height is incorrectly recorded. The expected accuracy of ground-based survey points is ±0.05 m, except in rare cases where points are surveyed in tree cover or near large vertical banks resulting in poor satellite coverage. The digital echo sounder used for the boat-based surveys has an accuracy of ±0.01 m under optimal conditions. Due to the pitch and roll of the boat, the expected accuracy of the boat-based survey is ±0.07 m. The collected survey data's accuracy in both ground-based and boat-based surveys falls within the expected accuracy specified in the FHIP Flood Study Technical Guidelines (AEP, 2022).

2.3.1 Coordinate System and Datum

Horizontal positions were referenced to the three-degree Transverse Mercator (3TM) projection with a central meridian of 114°W. The 3TM projection is part of the Canadian Spatial Reference System (CSRS) North American Datum of 1983 (NAD83), which 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 to be consistent with the specified project datum and geoid model.

2.3.2 Control Network

NHC established three semi-permanent benchmarks across the study area for primary survey control. Three GNSS receivers were run simultaneously in static mode for more than three hours to obtain CSRS precise point position (PPP) coordinates at each control point. The data were then post-processed using Trimble Business Center software to adjust the network by establishing baselines between control points. **Table 2-1** provides the adopted coordinates for the three established control points and three additional control points which were established to extend the range of the primary control network. The primary control network was constrained to the PPP coordinates for the NHC 2 control point, which had the longest occupation time and the lowest reported uncertainty. The horizontal and vertical error in the two other NHC control points after post-processing are summarized in **Table 2-2**.

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Table 2-1 Control point summary

Point Name	Type	Easting (m)	Northing (m)	Elevation (m)
NHC 1	Primary Control Network	-83.815	6504670.037	235.019
NHC 2	Primary Control Network	9086.641	6510146.843	235.926
NHC 3	Primary Control Network	20942.726	6508640.123	227.295
NHC 4[1]	Extended Control Network	12160.019	6507758.032	227.618
NHC 5[1]	Extended Control Network	4970.711	6509932.734	235.808
NHC 6[1]	Extended Control Network	5931.392	6511891.669	249.201

Table 2-2 Primary control network errors

Point Name	Easting (m)	Northing (m)	Elevation (m)
NHC 1	0.006	0.008	0.029
NHC 3	0.007	0.010	0.036

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2.4 Cross Sections and Bathymetry

Cross section locations were selected to ensure adequate representation of the channel geometry in the hydraulic model. Cross section alignments were determined ahead of the field program. Cross sections were positioned along the Peace River and Garden Creek to capture changes in channel pattern, widths, and slopes. Additional cross sections were placed at the upstream and downstream faces of bridges, and a few river widths upstream and downstream of the structures. The additional sections at hydraulic structures followed the geometry requirements for modelling bridges and culverts as recommended in the HEC-RAS documentation. Cross sections were surveyed over two separate visits in October 2024 and May 2025. The cross section locations are indicated in the survey overview maps provided in **Appendix B**.

A total of 108 cross sections were surveyed, 37 along the Peace River main channel, 10 along the Peace River side channel located between XS-11 and XS-25, and 61 along Garden Creek. To minimize uncertainties in the hydraulic modelling results caused by the downstream boundary conditions, the survey was extended approximately 12 km downstream and 2 km upstream of the Peace River study limit. **Table 2-3** provides a summary of the average, minimum, and maximum cross section spacing in each reach.

The survey point data were assembled and are provided separately with the digital study file.

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Table 2-3 Surveyed cross section summary

Reach	Reach Length (m)	Number of Cross Sections	Average Spacing (m)	Minimum Spacing (m)	Maximum Spacing (m)
Peace River – Main Channel	52,175	37	1,449	714	2,672
Peace River - Side Channel	25,340	10	2,318	827	7,135
Garden Creek	20,203	61	337	11	2,907

2.5 Hydraulic Structures

The hydraulic structures measured as part of the survey program include two bridges as listed in **Table 2-4**. The table also includes the corresponding Alberta Transportation and Economic Corridors (TEC) Bridge File (BF) numbers when available. No bridges or hydraulic structures crossed the Peace River within the surveyed reach.

Table 2-4 Hydraulic structure summary

Stream	River Station (m)	Crossing Description	Structure Type	TEC Bridge File Number
Garden Creek	1,006	Unnamed Road Bridge in Garden River	Bridge	79357
	10,501	Highway 58 Bridge	Bridge	79356

The locations of these structures are shown in the survey overview maps provided in **Appendix B**. Survey data collected for each bridge includes span length, deck width, low chord elevation, top of curb or solid guardrail elevation, and pier details. No bridge drawings were available for either bridge. Details on each structure and field photographs are provided in **Appendix C**.

2.6 Flood Control Structures

Flood control structures, also commonly referred to as flood berms, are defined by the provincial Flood Hazard Identification Program (AEP, 2022) as a *permanent barrier or engineered system that keeps water from entering and flooding an area.* These structures typically require regulatory approval prior to construction, receive routine inspection and maintenance, and are officially recognized by local authorities as flood management infrastructure. No flood control structures were identified in the study area.

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2.7 DTM Comparison to Survey Data

NHC completed a comparative analysis between the elevations of the LiDAR based DTM and the survey data. **Figure 2** shows the results of the comparison as a histogram with the expected range of accuracies for the DTM (± 15 cm) indicated. The survey points were separated into three classes: hard surfaces, ground, and banks. This is intended to capture the range of variances between the survey and DTM for different survey point types. For examples, points taken on flat hard surfaces are expected to have a lower variance and higher agreeance with the DTM than those in sloped vegetated areas along river banks. All survey data taken near or below the water surface were excluded from this assessment.

The comparative assessment shown in **Figure 2** indicates good agreement between surveyed elevations and the DTM, as most points fall within the expected accuracy range. Therefore, the DTM is considered suitable for use in the hydraulic modelling and flood mapping for areas where it was not feasible or safe to collect direct field measurements. It should be noted that the DTM skewed higher than the collected survey elevations. This could be due to several factors including the LiDAR not capturing low ground collected during the survey or the survey not collecting high points captured by LiDAR.

2.8 Additional Data

In addition to the collected DTM, aerial imagery, and survey data already mentioned, several other data sets were collected to assist in the modelling efforts. These additional data sets include discharge measurements, hydraulic structure design drawings, base mapping features, and field photographs.

2.8.1 Discharge and Water Level Measurements

As part of the survey program, NHC measured discharge and corresponding water levels at the Peace River and Garden Creek reaches. Discharge measurements were taken at two selected transects, one along both the Peace River and Garden Creek. Water levels were recorded surveyed at cross sections and are denoted as water level measurements within the survey data geodatabase.

The discharge measurements on Peace River and Garden Creek were collected using a Sontek RiverSurveyor-M9 Acoustic Doppler Current Profiler (ADCP) and Sontek FlowTracker Acoustic Doppler Velocimeter (ADV), respectively. The ADCP and ADV report velocities at an accuracy of ±0.20 cm/s and ±0.25 cm/s, respectively. **Table 2-5** summarizes the discharge measurements for the Peace River and Garden Creek. All measured discharges listed in **Table 2-5** are considered low flow discharges and are not representative of flood conditions.

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Table 2-5 Summary of discharge measurements

River	Date	Discharge (m^3/s)	Location Remarks
Peace River	8 October 2025	854	Located at XS 24 downstream of the confluence with Garden Creek. The side channel was not included in the discharge measurement as there was no discernable flow at the time of the survey.
Garden Creek	9 October 2025	0.24	Located at XS 43 upstream of the Highway 58 Bridge crossing.

2.8.2 Hydraulic Structure Design Drawings

No design drawings for either of the bridges listed in **Table 2-4** could be located for use in the modelling.

2.8.3 Base Mapping Features

In addition to the data 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 in the study area.

2.8.4 Field Photographs

Appendix D provides annotated reach representative field photographs that were obtained during the site inspection and survey program. The location, time, and other metadata information are embedded in the electronic images includes as part of the digital file submission.

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3 OPEN WATER FLOOD HYDROLOGY

This section presents the flood hydrology of the Peace River, focusing on the study area. It reviews the flood history, including both open water and ice jam flooding, and presents a flood frequency analysis for open water events. Flow estimation methods used for the flood frequency analysis are discussed, and the results are compared with previous studies along the river reach.

3.1 Flooding History

This section summarizes flooding events on the Peace River with a focus on Garden River. The community experienced high water most recently during the 2020 river ice breakup. Historical flood accounts are limited.

3.1.1 General Information

Flood history information for the local study area, and elsewhere along the Peace River, provides context for the hydraulic model development and calibration. Flood history information found for open water and ice jam flooding is presented below. Representative photographs of flood history found in this study are provided **Appendix E**.

3.1.2 Open Water Floods

Seasonal flow records were collected just upstream of the study area from 1960 to 1967 at historic WSC station Fifth Meridian (07KA002), located approximately 10 km upstream of Garden River. The closest WSC gauges with long-term hydrometric data are at Fort Vermilion and Peace Point, and their records form the basis for identifying the open water flood history at Garden River during the period of systematic monitoring within the study area. The WSC gauge station on the Peace River at Fort Vermilion (07HF001) was established in August 1915 and provides discharge records for the periods 1915–1922, 1961–1978, and 2006–present. Between 1979 and 1993, only water level records are published; streamflow over this period were estimated by NHC (2022) in a prior flood study. The WSC gauge station at Peace Point (07KC001) was established in 1959 and has continuously recorded both water levels and discharge since its installation.

Analysis of hydrometric records indicates that, between Fort Vermilion and Peace Point where the study area is located, annual peak discharges on the Peace River typically occur between late May and July as a result of snowmelt, with or without rainfall, though peaks may also occur in April or August. Data also reveals that during large flood events, peak flows are generally higher at Fort Vermilion than at Peace Point. Through the study area, the Peace River's slope flattens and the floodplain widens considerably, with side channels, oxbow lakes and meander scrolls. This provides for an increase in channel storage that contributes to the attenuation of flood peaks between Fort Vermilion and Peace Point.

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3.1.2.1 Recent and Recorded Open Water Floods

Recent and recorded floods are those floods associated with the systematic recording of water levels and discharge. The systematic record for the Peace River was previously mentioned in **Section 3.1.2**. For the purpose of this study, floods occurring during these periods are denoted as recorded floods. A description of these recorded floods is provided below. More details are available in the appended hydrology report.

Among the events mentioned in the appended hydrology report (**Appendix A**), the June 1990, July 2011, and June 1964 floods are the three largest, with the more recent July 2020 event ranking fourth in the period from 1915 to 2023. The following section summarizes these four major events in chronological order.

1964 Flood Event: The 1964 event ranks as the third largest open water flood within the study area of the Peace River. At Fort Vermilion, the flood occurred on 16 June, with daily discharges reaching 12,400 m^3/s. The flood wave reached Peace Point three days later, where a maximum daily discharge of 11,900 m^3/s was recorded at WSC Station 07KC001. No observations are available for this event at any of the communities along the reach.

1990 Flood Event: On 16 June, water levels at Fort Vermilion peaked at 253.68 m with a daily discharge of 13,200 m^3/s, although flooding at the site was minimal. According to AT Bridge File 74227, the high-water level at the Highway 88 bridge remained approximately 11 m below the deck. This flood resulted from concurrent high flows in the upper Peace and Smoky River basins. At the Town of Peace River, the Peace River flow peaked three days earlier on 13 June, marking the highest recorded discharge at WSC Station 07HA001. The flood reached Peace Point on 17 June, with a daily discharge of 12,600 m^3/s recorded.

2011 Flood Event: During the July 2011 flood, WSC Station 07HF001 (Fort Vermilion) recorded a maximum water level of 252.90 m, with a peak daily discharge of 12,700 m^3/s on 13 July. The Highway 88 bridge experienced lower water levels than during the 1990 flood (AT Bridge File 74227). The flood wave passed Garden River over roughly two days, reaching Peace Point on 15 July with a peak daily discharge of 10,900 m^3/s. Peak flows at the Town of Peace River (TPR) occurred two days earlier. The 2011 event showed greater attenuation between Fort Vermilion and Peace Point compared to 1990.

2020 Flood Event: The daily discharge at Fort Vermilion reached 12,300 m^3/s during the 6 July 2020 flood. No bridge information is available for this event, so the water's elevation relative to the Highway 88 bridge deck is unknown. The flood reached Peace Point two days later, with recorded daily discharges of 10,800 m^3/s.

3.1.2.2 Historic Open Water Floods

No historical observations of open water floods are available for Garden River. Some notable floods on the Peace River, including the 1914, July 1935, and May 1948 events, were

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documented at the Town of Peace River. The 1914 flood, in particular, was severe, with peak discharge approaching that of the 1990 flood at TPR. However, none of these events were reported at Fort Vermilion, Garden River, or Peace Point. Consequently, although these floods may have affected Garden River, there is no conclusive information to include them in the analysis.

3.1.3 Ice Jam Floods

Flood documentation regarding ice jam–induced events at Garden River is limited. Available reports and accounts primarily focus on past floods and monitoring programs at the Hamlet of Fort Vermilion. There is very limited flow data (at any time of year) nor information documenting floods at Garden River, however, it is generally recognized that the most significant floods along the Peace River within the study area are ice related. The limited information available was found from the ice observation reports published by EPA for the Peace River, which have included occasional references to Garden River since 2018. Information on the only documented pre-2018 event, the 1996 ice jam flood, appears in the Peace-Athabasca Delta breakup monitoring reports.

This section summarizes the available information on ice jam events at Garden River. References to documented events at the Town of Fort Vermilion and Peace Point are also included to provide additional context.

3.1.3.1 Recent and Recorded Ice Jam Floods

1996 Ice Jam Flood Event: Ice jam formation in the Peace River near Garden River began on 25 April, with the toe forming at Big Island, approximately 5 km downstream of the community. The jam extended about 35 km upstream of the community and remained in place for three days, until 28 April, when it began to move slowly. Ice jam formation resulted in elevated water levels along the Peace River within the community boundaries; however, no significant flooding was reported in the community.

2018 Ice Run Event: A significant ice jam formed at the Vermilion Chutes, located approximately 65–70 km upstream of Garden River. This jam mobilized in the early hours of 2 May, generating a heavy ice run within the study area. Event photographs indicate that ice was pushed into Garden Creek, affecting a bridge and road access; however, aside from this, the Peace River ice run remained largely confined within the banks.

2020 Ice Jam Flood Event: As breakup progressed down the Peace River past Fort Vermilion through Garden River on 29 April and stalled approximately 24 km downstream of Garden River, to form an ice jam. On 30 April, this jam caused flooding of roads and bridge access at Garden River, although no significant damage to houses or infrastructure was reported. By 1 May, the jam split into two smaller jams, which persisted until 2 May. Upon release in the early hours of 3 May, the resulting heavy ice run caused significant damage to the WSC gauge station at Peace Point.

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3.1.3.2 Historic Ice Jam Floods

Reports or documentation of historical flood events at Garden River were not found during this study. During major breakup sequences, multiple ice jams develop over long distances as breakup progresses down the Peace River below TPR, through Fort Vermilion and down to Peace Point. And so, over a long period of time, the frequency and severity of ice jam flooding at one location may be considered representative of the relative frequency and severity at other locations along the river.

Historical flood information was available for Fort Vermilion but was not found for Peace Point (only the recent flood information, described above).

A comprehensive analysis of the historic flood record available for Fort Vermilion was completed in a prior flood study (NHC, 2022) and are summarized below. The historic floods documented at Fort Vermilion give context for historic ice jam floods along the Peace River, including the Garden River area. The severity of ice jam flooding experienced at Fort Vermilion for any particular year may not necessarily well represent that experienced at Garden River; however, it is reasonable to consider the frequency of ice jam flooding at Fort Vermilion to be indicative of that at Garden River.

1876 Ice Jam Event- Ft. Vermilion: An ice jam flood occurred on 2 May 1876, at Fort Vermilion, with flood levels reaching an estimated peak water level of 254.8 m[1](Gerard and Karpuk, 1979). Historical accounts describe significant impacts to local residents, with free traders living on the island opposite the fort forced to evacuate and move their possessions to the roof of their dwelling (Thomson, 1993). The estimated peak level at the Hudson's Bay Company trading post provides the primary quantitative reference for this event. The potential impacts of the event and flooding conditions at Garden River remain unknown.

1888 Ice Jam Event- Ft. Vermilion and Garden River: An ice jam flood occurred from 7 to 9 May 1888, at Fort Vermilion, with an estimated peak water level of 258.7 m at the Hudson's Bay Company trading post[2] (Gerard and Karpuk, 1979). The flood was caused by an ice jam located ~45 km downstream of Garden River (AT Bridge File 74227) and was expected to have impacted the Garden River community. The flood level was reported to be comparable to, or higher than, the 1934 flood. No detailed information on the flood is available at Garden River.

1894 Ice Jam Event- Ft. Vermilion: The 1894 ice jam event near Fort Vermilion resulted in estimated water levels of 255.7 m at the HBC post (Gerard and Karpuk, 1979). Observations indicate that although the ice was forced up over the bank and water approached within

[1] The ice jam flood level estimate has been converted into geodetic elevation from "stage above zero flow elevation" presented by Gerard and Karpuk (1979).

[2] The HBC post is located near 45 Street by the Peace River, approximately 1.77 km downstream of WSC Station 07HF001.

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approximately three feet of the top, no significant flooding occurred as the ice began to move before spilling over (Thomson, 1993). No information is available regarding impacts at Garden River.

1934 Ice Jam Event- Ft. Vermilion: The 1934 ice jam event near Fort Vermilion, dated 22 April, resulted in estimated water levels of 258.4 m at the HBC post (Gerard and Karpuk, 1979). According to long-term residents, this event was the most severe flood experienced since 1917 (AENV, 1968). The ice jam, located approximately 3.2 km downstream of the town, caused water depths of about 0.6 m at the HBC post and 1.8 m near the present-day Wop May Memorial Aerodrome. No information is available regarding the impacts at Garden River.

1950 Ice Jam Event- Ft. Vermilion: The 1950 ice jam event on 7 May produced a peak water level of approximately 252.3 m at the Fort Vermilion HBC post (Gerard and Karpuk, 1979). Photographs from the Experimental Farm, documented in AT Bridge File 74227, show elevated ice levels along the riverbanks. The event is not believed to have caused significant flooding impacts. No information is available for Garden River.

1963 Ice Jam Event- Ft. Vermilion[3]: The ice jam event of 23 May 1963 produced a peak water level of approximately 255.4 m at the Fort Vermilion HBC post (Gerard and Karpuk, 1979). According to a long-term resident, roads near the airport were covered by about 0.6 m of water (AENV, 1968). AT Bridge File 74227 estimates a flood level of 254.2 m on the approach to the south side of the ferry crossing. No information is available for Garden River.

3.2 Open Water Flood Frequency Analysis

3.2.1 Flood Frequency Flow Estimates

A key outcome of the open water hydrology assessment (attached as **Appendix A**) was the estimation of the open water flood frequency magnitudes for the Peace River and Garden Creek. The results of the flood frequency analysis are reproduced here in **Table 3-1**. The hydrology completed for this study also included estimation of flood frequencies for Peace Point for comparison.

The flood frequency analysis relied on naturalized flood peak discharges for the Peace River at Fifth Meridian that were estimated by routing the naturalized flows from Fort Vermilion to Peace Point, together with tributary inflows and gauge corrections. The routing analysis was performed at a daily time step using HEC-ResSim of the U.S. Army Corps of Engineers. Routed daily discharge estimates over the breakup period – these estimated values were used to estimate discharge for calibration of the ice enhanced model.

[3] The WSC operated the gauge 07HF001 in 1963, but the record was incomplete; so the 1963 event has been deemed as a historic event.

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Table 3-1 Flood frequency estimates for Peace River at Fifth Meridian and Garden Creek at the mouth under natural/naturalized conditions

Open Water Flood	Peak Instantaneous Discharge (m^3/s)			
	Peace River at Fifth Meridian		Garden Creek at the mouth	
	Value	Upper 95% Limit Lower 95% limit	Value	Upper 95% Limit Lower 95% limit
1:1000	24,300	28,200 21,700	158	186 138
1:750	23,500	27,100 21,000	152	178 133
1:500	22,400	25,600 20,100	142	167 124
1:350	21,400	24,400 19,300	134	157 117
1:200	19,900	22,500 18,100	121	142 106
1:100	18,200	20,300 16,700	105	123 92.4
1:75	17,500	19,400 16,200	98.8	115 86.9
1:50	16,600	18,200 15,300	89.3	104 78.6
1:35	15,700	17,200 14,700	81.3	94.3 71.6
1:20	14,500	15,600 13,600	68.4	79.2 60.3
1:10	12,900	13,800 12,200	52.7	60.9 46.2
1:5	11,400	12,000 10,900	37.1	43.3 31.6
1:2	9,200	9,610 8,810	16.8	22.1 11.1

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3.2.2 Comparison to Previous Studies

No previous flood frequency estimates exist for these two sites. NHC (2022) developed estimates for the Peace River at Fort Vermilion, about 150 km upstream, and flood frequency estimates were completed under this study for Peace Point, about 160 km downstream. These are compared with the Peace River at Fifth Meridian in **Table 3-2**. Differences among the three sets of estimates are small. For return periods beyond 100 years, flood peaks at Fifth Meridian are slightly lower than at Fort Vermilion and slightly higher than at Peace Point.

Table 3-2 Comparison with previous flood frequency estimates for Peace River at Fort Vermilion and Peace River at Peace Point

Open Water Flood	Peak Instantaneous Discharge (m^3/s)		
	Peace River at Fort Vermilion (NHC, 2022)	Peace River at Fifth Meridian (This Study)	Peace River at Peace Point (This Study)
1:1000	24,700	24,300	23,700
1:750	23,800	23,500	22,900
1:500	22,500	22,400	21,800
1:350	21,500	21,400	20,900
1:200	19,900	19,900	19,500
1:100	18,100	18,200	17,900
1:75	17,300	17,500	17,200
1:50	16,300	16,600	16,300
1:35	15,500	15,700	15,500
1:20	14,100	14,500	14,300
1:10	12,600	12,900	12,800
1:5	11,000	11,400	11,300
1:2	8,830	9,200	9,200

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4 OPEN WATER HYDRAULIC MODELLING

This section provides an overview of the open water 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

The hydraulic modelling relied on data collected during this study as well as any relevant data available prior to this study. Existing data was limited which presented a key challenge for this flood study. To overcome these challenges the study adopted several assumptions as described in **Sections 4.3.1** and **4.3.3**. The proceeding sections describe the available data prior to the study and collected data during the study.

4.1.1 Survey & Base Data

Development of the model geometry relied primarily on the survey and base data. Survey data was comprised of the surveyed channel and hydraulic structure data. The base data used to develop the model geometry included the DTM, 2023 SPOT 6 Imagery, and base mapping information. Channel survey data was used to define the one-dimensional (1D) in-channel geometry for the Peace River main channel. Additionally, channel survey data for the Peace River side channel and Garden Creek was incorporated into the DTM to create a modified terrain for the two-dimensional (2D) model that is representative of both the channels and the floodplain areas. The methods used to develop the modified terrain are detailed in **Section 4.3**. Hydraulic structure data collected during the survey was used to code the bridge geometries into the hydraulic model. Base mapping data, aerial imagery, and the DTM were referenced during model creation to align hydraulic structures and digitize breaklines during creation of the 2D model domain. The 2023 SPOT 6 Imagery was referenced when delineating various land use classification areas for estimation of model Manning's roughness values in both the channel and overbank areas.

4.1.2 Existing Models

No prior provincial flood hazard mapping exists for Garden River; therefore, no hydraulic model has previously been developed to the standards outlined in provincial flood mapping guidelines.

4.1.3 Highwater Marks

Highwater mark (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 within the study area. To gather highwater

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mark data, which is associated to open flood events, various sources such as previous studies, the EPA database, flood history documentation from AT, and local historical archives were thoroughly searched. Unfortunately, no highwater mark data associated with open water flood events was located for the study area.

4.1.4 Gauge Data & Rating Curves

The relationship between stage (water level) and discharge at a gauging station is established by the Water Survey of Canada (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.

Long-term flow or water level data are not available for the Peace River within the study area. A discontinued WSC gauge station, 07KA002 (Peace River at Fifth Meridian), was located near the upstream boundary of the study area; but it provided only partial daily flow records for the periods of 1960-1964 and 1966-1967. WSC provided some historic water level and discharge measurements for the discontinued Peace River at Fifth Meridian gauge (07KA002). However, the water level data was recorded based on a local datum and no conversion factor was provided to convert the water level data to geodic elevations. As such, the data cannot be used as part of the model calibration.

4.1.5 Flood Photography

Aerial flood photography was found for some ice jam related events as discussed in the following sections. There was no flood photography found for open water events.

4.1.6 Sentinel-2 Satellite Imagery

Sentinel-2 satellite imagery was inspected for recent flood events. Imagery was available for the July 2020 event with clear images captured on 6 and 8 July 2020. This imagery was used to inform model calibration. The estimated Peace River flows at Garden River ranged between 10,000 m^3/s and 11,200 m^3/s on those dates which is greater than the 1:2 open water flood (9,200 m^3/s) but slightly smaller than the 1:5 open water flood (11,400 m^3/s). Flows were estimated by the routing model used for flow naturalization, as described in the hydrology reporting (refer to **Section 3.2.1**).

4.2 River & Valley Features

This section describes the channel and floodplain characteristics of the Peace River and Garden Creek within the study area.

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4.2.1 General Description

The study area consists of a 47 km segment of the Peace River beginning just west of the boundary of Mackenzie County and Wood Buffalo National Park, which is located about 16 km upstream of Garden River. The location of the study area was previously shown in **Figure 1**. Garden River is the most developed and populated area along this reach of the Peace River. Also included in the study area is a 20 km reach of Garden Creek upstream of its confluence with the Peace River.

The Peace River generally flows through the study area from the west to the east. The river is entrenched and confined within a valley of about 30 m deep. The area surrounding the valley is predominantly covered by a mixed forest, characterized by a variety of both deciduous and coniferous trees. The river valley has a width of approximately 4.5 km near the upstream boundary and then quickly widens to a width of about 15 km roughly 12 km upstream of Garden River along the Peace River. The widened valley extends to the downstream boundary.

Further details regarding the river channel and valley features are provided below.

4.2.2 Channel Characteristics

Peace River

The Peace River is a partly entrenched and confined channel within the study area with its main channel being about 690 m wide on average. The river planform carries an irregular meander pattern that is confined by terraces throughout the study area. Several large, vegetated islands are located within the study area, resulting in the river channel being split into two or three subchannels. The upper reach of the Peace River extends from the upstream boundary of the study area to river kilometer 23 and has a water surface slope of approximately 0.0001 m/m. In the lower reach downstream of river kilometer 23 the water surface slope is shallower with an average of about 0.000035 m/m to river kilometer 0. The riverbed is predominantly comprised of sand.

Garden Creek

Garden Creek within the study area is a natural meandering channel. The upstream section of Garden Creek within the study area flows in southwest direction towards Hwy 58 and exhibits a fairly defined channel with often indistinct banks that are vegetated with shrubs and trees. The planform within this reach exhibits mostly irregular meanders with a series of meander bend cutoffs and oxbows. Water levels at low flows are controlled by several beaver dams that backwater into the adjacent floodplain. The channel slope varies within the upper reach from 0.0012 m/m upstream of river kilometer 18 to 0.0001 m/m in the mildly sloped reach at Hwy 58. The average bankfull width and associated average channel depth is about 16 m and 2.4 m respectively.

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Along the reach downstream of Hwy 58, the creek continues in a mostly south-eastern direction. The channel slope varies along this reach, from 0.0001 m/m in the mildly sloped reach near Hwy 58 to 0.002 m/m in the steeper sloped reach near the Unnamed Road Bridge. The meander pattern changes to more regular meanders as the valley becomes more incised at around 4 km upstream of the confluence with the Peace River. The average bankfull width is about 17 m along both the upper flatter reach and lower steeper reaches; the average bankfull depth is about 2.7 m along the upper wider reach and increases to about 2.9 m along the lower narrower reach.

4.2.3 Floodplain Characteristics

Peace River

The Peace River has established a stream-cut valley with distinct valley walls formed to the north and south. In the upper reach, the valley has an initial width of approximately 4.5 km. At approximately river kilometer 43 (about 12 km upstream of Garden Creek) the valley widens to a width generally around 15 km for the remainder of the study area. The valley floor has a low gradient and contains several floodplain features including meander scrolls, oxbows, side channels, and abandoned channels. These features hydraulically activate during high flow events conveying a significant portion of flow outside the main channel of the Peace River.

The valley walls and floodplains are predominantly characterized by a mixture of boreal forest and marshland with limited development around the community.

The community of Garden River is located on the northern floodplain of the Peace River. The community is situated on a terrace, with the northern half approximately 3 m to 4 m above the southern half of the community. Part of the upper terrace slopes towards the southwest and has been shaped by the movement of Garden Creek.

Garden Creek

The floodplain of the Garden Creek study area begins near the uplands at the base of the north valley wall (river kilometer 20 of Garden Creek), north of the community of Garden River. The floodplain is relatively wide (about 450 m) and marshy within this upper reach between Hwy 58 and the upstream model limit. There are several depressions and cutoff channels throughout this reach that are backwatered by beaver dams. The floodplain width varies between roughly 50 m to 230 m in the lower reaches of the study area between Hwy 58 and the confluence with the Peace River.

Upstream of Hwy 58, the landcover of the floodplain consists generally of shrubbed vegetation with a few wetland areas within the low-lying dominant portion of the floodplain which transitions to trees in the more elevated portions of the terrain. Downstream of Hwy 58, the channel is generally more incised, and trees primarily border the bank's edges.

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4.2.4 Anthropogenic Features

Development in and around Garden River present the dominant anthropogenic features within the study area. The following lists predominant features within the study area. They are listed generally from upstream to downstream.

- Floating timber pedestrian bridge near the upstream boundary of Garden Creek.
- Various low-density developments alongside the left bank of Garden Creek.
- Sewage lagoons alongside the left bank of Garden Creek, north of the Garden River Airport.
- Logging road that runs from Hwy 58 alongside the right bank of Garden Creek in upstream direction.
- Three span bridge structure that crosses Garden Creek at Hwy 58.
- Borrow pit and landfill area south of Hwy 58 and north of Garden Creek.
- Buried pipeline crossing and corridor on Garden Creek.
- Garden River industrial including Garden River Airport north of the community.
- Three span bridge structure that connects the communities' north and south residential areas.
- Sister Gloria School and adjacent recreational area.
- Garden River residential areas including the lagoons south of Garden Creek and north of the Peace River.

4.3 Model Construction

This section describes the hydraulic model development including its methodology, geometric components, selection of model parameters, model results, and model sensitivity analysis.

4.3.1 Methodology

The U.S. Army Corps of Engineers Hydrologic Engineering Center-River Analysis System (HEC-RAS) computer program (Version 6.6 September 2024) was used to calculate the flood levels within the study area. HEC-RAS can perform hydraulic calculations for 1D, 2D, or coupled 1D/2D models.

For this study, a coupled 1D/2D model was used to simulate flows in the Peace River main channel and complex flow patterns in specific overbank areas. The Peace River main channel was represented in the 1D domain and flow over complex overbank areas were modelled in the 2D domains. The 2D modeling approach of the overbanks provided a more realistic representation of the overbank flow pattern and corresponding water surface profile than could otherwise be represented with 1D cross sections extending from the main channel and into the overbank areas. The 1D and 2D domains were coupled together with lateral flow structures to allow for the exchange of flow between these domains.

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Garden Creek was included in the 2D model domain representing the left overbank area. The 2D modelling approach provides a more realistic representation of overland flow during larger flood events. Specifically, in cases where flow overtops the main channel banks and utilizes abandoned channels in the floodplain thus shortening the stream lengths of the channel. An example is shown for the Garden Creek reach downstream of Hwy 58 in **Figure 3**. A lateral structure was assigned at the confluence of the Garden Creek with the Peace River to connect the two reaches.

Figure 4 provides a schematic of the various model elements. The methods used to develop the various model components are detailed below.

4.3.1.1 1D Domain

The 1D domain for the 47 km reach of the Peace River was digitized using ArcGIS tools along the channel centreline. The alignment of the channel centreline was determined through visual reference of the DTM and aerial imagery. Flow paths are required by the model to determine the streamwise distances along the main channel and overbank areas. The model requires these distances for calculation of energy losses between cross sections within the main channel, left overbank, and right overbank areas. The main channel flow path was created coincident with the river centerline.

Model cross section transects were digitized at each surveyed cross section. The main channel portion of the section was digitized perpendicular to the main channel alignment and in line with the surveyed channel and bank point data. The cross sections were extended far enough left and right to reach the top of the riverbank or elevated feature. Cross section elevation values from the survey point data were projected perpendicularly onto the cross sections. Additional elevations outside the channel portion covered by the survey data were extracted using the underlying DTM. The number of elevation values across the cross section were filtered to within the HEC-RAS limit of 500 points.

The left and right bank stations were determined by inspecting the cross section geometry and examining DTM channel geometry. Bank stations demarcate the extents of the modelled left overbank, main channel, and right overbank portions of cross sections. The 1D overbank areas include subchannels of the Peace River and vegetated islands and generally extend to high terraces or elevated features that confine the Peace River flow outside of river confluences.

4.3.1.2 Terrain Modifications

To facilitate the 2D modelling of channel features and overbank areas outside of the available DTM, three separate terrain models were created during the model construction – all of which were created with tools available in the HEC-RAS Mapper environment (RAS Mapper).

The first, a bare-earth-terrain, was created from the LiDAR-based bare-earth DTM provided by EPA. The bare-earth DTM provides a land surface that excludes all features projecting above

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grade such as trees, buildings, and bridge decks. However, no corrections are made to capture land surfaces below water (streams and water bodies). And so, the elevations over the channel portions of the Peace River and Garden Creek are indicative of the elevation of the water surface covering these hydrographic features as they existed during the LiDAR acquisition program.

The second terrain was based on the bare-earth-terrain modified to account for the geometries within the main channel portions of Garden Creek and a 720 m long side channel of the Peace River which transects the right overbank area. The first step was to create a terrain within the extents of the main channel geometry. This main channel geometry terrain was then merged into the bare-earth-terrain to replace those portions, below the water surface, that were not captured under the LiDAR survey program. The processes outlined in the HEC-RAS Mapper User's Manual (Hydrologic Engineering Center, 2025a) and previously discussed in **Section 4.3.1.1** for the Peace River main channel were used to create the channel terrain from surveyed cross sections. In addition, HEC-RAS's cross section interpolation tool was used to interpolate cross sections between two selected survey cross sections. This was necessary to fill larger data gaps along Garden Creek and to ensure that constrictions or abrupt channel changes were captured within the model domain. The overbank areas on the interpolated cross sections were updated based on the underlying DTM to represent the local terrain conditions. The interpolated main channel portions were carefully reviewed and manually shifted where necessary using HEC-RAS's Graphic XS Editor tool to ensure the main channel was reasonably represented and transitions between the main channel and the overbanks were smooth.

A third terrain was constructed to fill gaps in DTM coverage at the northeast and southwest corners of the Peace River overbank areas. Preliminary lower resolution LiDAR-based-bare-earth DTM was disregarded since it did not vertically align with the most recent DTM although the data covered the southwest overbank area outside the new DTM. The third terrain was constructed with the RASMapper terrain modification tools. The backwater channels, overbanks, and valley wall alignments were based on the terrain data adjacent to the missing data areas and SPOT imagery within the missing data areas. The elevations of the constructed features were interpolated across the missing data areas between the known elevations of the adjacent terrain data.

The channel terrain and constructed third terrain were then merged into the bare-earth-terrain to create the final 2D-model-terrain. The portion of the terrain within the main channel was synthesized by interpolation of the main channel between surveyed and interpolated cross sections. The synthesized main channel portion was informed by smoothed banklines auto generated in RAS Mapper between surveyed cross sections which were developed with the intent of enhancing the surface development process. **Figure 5** and **Figure 6** provide illustrative comparisons between the original bare-earth terrain to the final 2D-model terrain created for modelling purposes. The first comparison highlights the inclusion of synthesized channels particularly along the Garden Creek reach while the second comparison shows the filled gaps in the DTM coverage at the southwest corner of the Peace River overbank area.

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The resulting 2D channel geometry provides an analogue that is hydraulically similar to the real 2D channel geometry. That is, flood profiles computed along the synthesized 2D channel geometry are consistent with those computed by a 1D model created from the surveyed and interpolated cross sections. The 2D-model-terrain is well-suited for computation of flood level profiles along the synthesized channels that include Garden Creek and the Peace River side channel. Along the Peace River side channel, the extent of the main channel is visible in the orthophotos and bare-earth-terrain. Along the Garden Creek, portions of the main channel were sometimes obscured by backwater behind beaver dams. This was especially apparent within the upper reach. Consequently, the alignment of the stream could only be estimated through these areas, and thus, the channel portion of the 2D-model-terrain does not necessarily follow the actual channel alignment.

4.3.1.3 2D Domains

The 2D domains represent the left and right overbanks of the Peace River. The right overbank area also includes the Peace River side channel while the left overbank area also includes Garden Creek and the community of Garden River.

The 2D domains are comprised of a computational mesh with polygonal cells of varying shapes and sizes. The geometry of the computational mesh was derived from the underlying DTM. The meshes for both the right and left overbanks were developed in an iterative manner to establish appropriate domain extents and mesh sizes while maintaining a practical size for computational purposes. The final left and right overbank 2D computational meshes comprised of approximately 63,000 cells and 26,000 cells respectively.

The 2D domain extents were initially set to flows that are commensurate with the estimated 1:1000 open water flood overflows. The two domains of the meshes were then reduced to limit dry areas to improve computational efficiency.

Mesh sizes within the 2D domains began with coarse meshes and were then progressively reduced to simulate the hydraulics at different scales. Ultimately the mesh sizes for both 2D domains were set to a nominal 100 m by 100 m grid. Mesh sizes within the Garden Creek floodplain was further reduced to a 10 m by 10 m grid to better capture the hydraulic conditions.

Breaklines were introduced along smaller channels coincident with the channel centrelines. These channel breaklines aligned cell faces orthogonal to the flow in the main channel and over the banks and allowed reduced cell spacing to better represent hydraulics at smaller scales. Cell spacing was reduced to 5 m for Garden Creek and 50 m for the Peace River side channel. Additional breaklines were incorporated throughout the model for elevated terrain features. Breaklines along elevated terrain features align cell faces to accurately capture the high ground. As a result, computations to adjacent cells beyond these elevated features occur only once flood levels exceed the high ground feature. These breaklines were used primarily within the left overbank area for roads, berms, ridges, and other natural high ground features. Breaklines were

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also incorporated for sub channels within the constructed third terrain to improve observed computational errors during initial runs.

4.3.1.4 Lateral Structures (1D/2D Coupling)

The 1D and 2D domains were coupled together with lateral structures. Lateral structures were placed at locations where flows would pass between the 1D and 2D domains and aligned along high terraces or elevated features. The model requires the crest of the lateral structure to be equal to or a higher elevation than the adjacent (connecting) 2D cells. The length of the lateral structures was limited to span the distance along a maximum of three cross sections.

NHC adopted the 2D flow computation method over the default weir method for modelling lateral structures. This approach was selected due to the absence of major linear road features where broad-crested weir flow behaviour typically occurs. The lateral structures were generally positioned along high points on the banks. These high points are overland features that typically do not function like weirs. Moreover, during larger return period events, the lateral structures become highly submerged. According to the HEC-RAS 2D User's Manual (Hydrologic Engineering Center, 2025b) this approach improves model stability during high submergence and more accurately represents flow leaving the 1D domain. The 2D flow computation method uses the 1D water surface elevation as a stage hydrograph when the water level exceeds the lateral structure at a 2D cell face and then applies flow to the 2D domain using the shallow water equations.

4.3.1.5 Channel (1D) and Overbank (1D and 2D) Roughness

Manning's roughness values were used to simulate energy loss in the modelled reaches. 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 values were held constant for the full range of discharges. The Manning's roughness values adopted for the present study are discussed further in a subsequent section on Model Parameters & Options.

4.3.1.6 Bridges

Bridges were solely located in the 2D domain of the model and were incorporated using *2D Area Connections*. The connection alignments coincided with the bridge centrelines and its extents with the opening through the road embankment. The bridge geometries were entered within the HEC-RAS geometry editor in the typical manner for bridges in a 1D model. The positioning and geometry data entered were based on the survey data and available design drawings.

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4.3.1.7 Expansion and Contraction Coefficients

To account for the effect of flow contraction or expansion losses on the energy balance between successive cross sections, HEC-RAS multiplies the absolute difference in velocity head by a coefficient. These coefficients range from 0.1 for gradual transitions to 1.0 for abrupt transitions. Contraction and expansion loss coefficients at cross sections immediately adjacent to bridges were set to 0.3 and 0.5, respectively, to represent the mild flow area obstruction associated with the bridge piers and abutments. For this study, there were no abrupt transitions identified and default values of 0.1 and 0.3 for contraction and expansion loss coefficients were used at all other cross sections.

4.3.1.8 Boundary Conditions (1D and 2D)

Boundary conditions are required at the inflow (upstream) and outflow (downstream) boundaries of the model. The inflow boundary condition is the discharge. The outflow boundary condition is a water level that can be set explicitly, estimated by the model for a given slope (by a normal depth approximation), or by a user-defined rating curve relationship.

The model included two separate inflow boundaries: one for the 1D domain of the Peace River and one for Garden Creek (left overbank 2D domain). At the model's downstream end, it included three separate outflow boundaries on the 1D domain of the Peace River, the right overbank 2D domain and the left overbank 2D domain.

Inflow hydrographs were specified at the inflow boundaries of the model for both the Peace River and Garden Creek reaches with sustained peaks that corresponded to the adopted flood frequency values as previously outlined in **Table 3-1** until a quasi-steady state solution was achieved. Further details on the computation period and criterion for a quasi-steady state solution are described in **Section 4.3.4**.

The downstream boundary of the 1D domain of the Peace River was set to a rating curve that was representative of the main channel reach. This rating curve was developed by supplementary 1D HEC-RAS modelling of the Peace River which extended an additional 38 km downstream of the coupled 1D/2D model boundary, beyond the limits of the LiDAR based DTM. The floodplain extent, channel width, and alignment for the extended reach were informed by the medium resolution DEM data from NRCAN and SPOT imagery. Elevation values in the floodplain were estimated from the medium resolution DEM data. The main channel was approximated by a rectangular geometry with elevation values extrapolated from the lower portions of the surveyed study reach.

The downstream boundaries of the left and right 2D domains were set to a normal depth approximation with a slope of 0.000035 m/m, a value that well-approximated the water surface profile for the surveyed water levels and DTM data along the lower reach of the Peace River.

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4.3.2 Geometric Data Base

All the HEC-RAS model geometry components were assembled into a geometric database and provided with the study electronic deliverables. These components include point and vector features for: survey data, extents of the model domain, channel centreline, flow paths, bank lines, breaklines, river stationing bank stations, and bridge locations. Model components were developed using standard ArcGIS geospatial tools and the built-in HEC-RAS geometry tools found in the RAS Mapper utility. The key hydraulic model elements included in the geometric database are depicted in **Figure 4** and further discussed below.

4.3.2.1 Cross Section Data

A total of 35 cross sections were developed for the 47 km long Peace River channel reach with an average cross section spacing of around 1.4 km.

A project river station convention (River KM) was established for the 1D channel of the Peace River which begins at the most downstream modelled cross section coinciding with the mapping domain for the coupled 1D/2D model and is expressed in kilometers. The associated model river stations are estimated from the river centerline. The river centerline extends approximately 38.5 km downstream of the 1D/2D model boundary (at river kilometer 0) to include the supplemental 1D model reach used to develop the downstream boundary condition (described in **Section 4.3.1.8**). **Table 4-1** lists the model river stations and corresponding project river kilometers along the Peace River, rounded to the nearest tenth. All river stationing discussed herein will refer to the project river station convention expressed in kilometers.

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Table 4-1 Peace River model river stations relative to project river kilometer

Model River Station (m)	River KM	Model River Station (m)	River KM	Model River Station (m)	River KM
85877	47.4	70138	31.7	53260	14.8
83205	44.7	68796	30.3	51692	13.2
81805	43.3	67520	29.1	50702	12.2
80635	42.2	66256	27.8	49464	11.0
79445	41.0	65243	26.8	48119	9.7
77954	39.5	64194	25.7	46856	8.4
76622	38.2	62832	24.4	45592	7.1
75565	37.1	61247	22.8	44372	5.9
74073	35.6	59712	21.3	42534	4.1
72757	34.3	58037	19.6	40674	2.2
71729	33.3	56529	18.1	38461	0.0
70852	32.4	55069	16.6		

4.3.2.2 Bridges

The constructed model comprises two bridge crossings: the Hwy 58 Bridge and the Unnamed Road Bridge. The bridges are located in the 2D domain with details of its incorporation previously described in **Section 4.3.1.6**.

Key design information of these structures that was incorporated into the model, included: abutments, high and low chords defining the bridge deck and the superstructure, and the arrangement, shape, and dimensions of the piers.

4.3.3 Model Calibration

Model calibration involves the selection and adjustment of model parameters such that calculated flood levels agree well with observed flood levels. For this study, calibration efforts focused solely on the channel roughness parameter for the Peace River. The roughness was adjusted until simulated water levels agreed well to observed water levels. No calibration was completed for Garden Creek due to a series of beaver dams which controlled flow conditions during low flows. The geometry and location of these beaver dams change frequently, particularly during flood events which prevents a reliable calibration of Garden Creek.

The primary challenge affecting calibration efforts was the absence of highwater mark data for open water flood events within the study area to compare against simulated water levels. Calibration efforts relied on low flow events confined within the Peace River banks with

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discharges significantly below the 1:2 open water flood discharge of 9,200 m^3/s. Two different water surface profiles were extracted for the Peace River from the LiDAR DTM which was collected on 27 May 2024 and 13 June 2024. The mean daily flows for these dates were estimated as 1,322 m^3/s and 1,851 m^3/s respectively, utilizing the HEC-ResSim routing model for the Peace River (refer to **Section 3.2.1**). A comparison of the computed water levels to the extracted LiDAR surface in HEC-RAS is shown in **Figure 7**.

It is expected that some elevation errors are present within the non-hydroflattened LiDAR water surface profile as wet surfaces typically reflect a LiDAR pulse differently than dry ground. The precision is low along the water surface profile, with differences between the upper and lower limits ranging from 0.1 m to 0.2 m. The extracted profile can be expected to provide a reasonable representation of the water surface during the time of the LiDAR flight within these differences. Therefore, this data quality is not comparable to that achieved by topographic GPS surveys and should be interpreted with caution.

For a more accurate calibration comparison, water level measurements collected as part of the survey by NHC between 3 to 8 October 2024 were also used. The measured discharge of 854 m^3/s on 8 October 2024 was applied as the inflow boundary for the model simulation (for comparison NHC's routed daily discharge estimate was 878 m^3/s, on that same day). Water levels were surveyed at each cross section, typically along both the left and right water's edge. A comparison of the surveyed water surface profile to the simulated water surface profile using the discharges below can be found in **Figure 7**. The computed water surface profile underestimates observed water levels by up to 0.24 m in the lower part of the reach primarily where water levels were surveyed between 5 to 6 October 2024. It is plausible this variance is due to higher flows during that period relative to 8 October 2024. NHC's routed daily discharge estimates varies between 897 m^3/s to 908 m^3/s during 5 to 7 October 2024 compared to the routed daily discharge of 878 m^3/s on 8 October 2024. The computed water surface profile agreed well to the observed water levels in the upper reach which were primarily collected on 4 October 2024. This is likely due to comparable flow conditions, inferred by the routed daily discharge estimate varying by only 3 m^3/s (881 m^3/s) on 4 October 2024 to 8 October 2024 (878 m^3/s).

Comparison to 2020 Imagery

With model calibration being limited to low flow events, efforts were made to compare model results during higher Peace River discharges using publicly available data. Sentinel-2 satellite imagery with low cloud cover was identified for 6 and 8 July 2020, capturing a summer flood event.

A unit daily hydrograph series for the July 2020 event was derived from the HEC-ResSim routing model (previously discussed in **Section 3.2.1**) for the Peace River. The maximum daily average discharge reached 11,621 m^3/s on 7 July 2020, slightly exceeding the estimated 1:5 open water flood instantaneous discharge of 11,400 m^3/s. This unit hydrograph series was applied as the

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inflow for the Peace River reach. A separate hydrograph with a sustained peak equivalent to the estimated 1:2 open water flood discharge of 16.8 m^3/s was applied to the Garden Creek.

Figure 8 and **Figure 9** compare simulated flood inundation extents for 6 and 8 July 2020, with the corresponding Sentinel-2 imagery. The Sentinel-2 imagery were manually georeferenced and some misalignment between the images and simulation extents are expected.

The simulated inundation extents generally provide a good match along backwatered tributaries, oxbows and at higher island locations. Other areas including shallower islands show greater inundation in the simulations as compared to the satellite image. There are several reasons why the simulation results may show greater inundation as compared to the satellite images. Firstly, the satellite sensors may not be able to detect floodwaters in denser vegetation areas as the signal is obstructed by the canopy. The difficulty in distinguishing flooded from non-flooded areas would be particularly challenging in shallow water areas with submerged vegetation. Secondly, there is inherent uncertainty in the estimated Peace River discharge rate for the dates of the satellite images. The Peace River at Fort Vermilion (07HF001) WSC gauge showed a relatively quick rise in flow during the summer 2020 flood event. So, it is possible that the simulated daily discharge values overestimate the peak conditions.

4.3.4 Model Parameters & Options

The following lists model parameters and options including Manning's roughness values and computational options. Unless otherwise stated, HEC-RAS default values were adopted for all model input and run parameters.

Manning's Roughness Coefficients:

Manning's roughness values were based on a land use classification. Each 1D cross section was classified by a minimum of three (one channel and two overbank) roughness values. Where appropriate, roughness was varied horizontally across the section to capture changes in river and floodplain characteristics. Individual land use types were selected for the 2D domain as shown on **Figure 10**.

Table 4-2 lists the channel Manning's roughness values for each river reach. The roughness values for the channels were initially based on field observations and available literature by Chow (1959). These values were then adjusted to better match observed water levels during open water calibration (as described in **Section 4.3.3**). The Peace River side channel Manning's roughness was informed by the calibrated Manning's roughness for the Peace River main channel. The Manning's roughness for Garden Creek was assigned following guidance provided by Chow (1959).

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Table 4-2 Calibrated channel roughness values

Reach	Manning's Roughness
Peace River Channel (1D)	0.026
Peace River Side Channel (2D)	0.026
Garden Creek Channel (2D)	0.040

The land use types for floodplain areas were determined from a combination of field observations and SPOT 6 aerial imagery. The classification includes open water, wetland, developed (low intensity), shrubs, and trees. **Table 4-3** summarizes the different floodplain land use types with their corresponding assigned Manning's roughness and the recommended ranges from literature. All floodplain land use types listed apply for areas within the 2D domains unless otherwise noted.

Floodplain Manning's roughness ranges for 1D cross sections follow values prescribed by Chow (1959). Initial 2D Manning's roughness values and ranges for the floodplain were based on the HEC-RAS 2D User's Manual (Hydrologic Engineering Center, 2025b). These values were further reduced according to Arcement and Schneider's (1989) adjustment factors for 2D floodplain conditions, which account for irregularity, obstruction effects, vegetation density and meandering.

All assigned floodplain Manning's roughness values tend toward the lower end or slightly below the ranges listed in **Table 4-3**, with the exception of Manning's roughness values assigned for the *open water* land use type. This is supported by initial model testing with roughness values tending toward the middle range of values which produced unrealistically high flood levels that would result for extreme floods with flows overtopping the valley walls and extending to the limits of the domain of available terrain data. The reduction in Manning's roughness values also allows for increased conveyance afforded by the abandoned channel paths and meander scrolls. The reduced values account for the relatively deep floodplain flows experienced during moderate to extreme floods. The values reported in the literature serve as a guide and it is plausible that the Manning's roughness values reported may not be representative of the very wide flat Peace River valley in our study area.

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Table 4-3 Land use types and Manning's roughness in floodplain areas

Land Use Type	Description	Values Listed in Literature	Assigned Manning's Roughness
Open Water	Areas of ponded open water, generally with less than 25% cover of vegetation or soil.	0.015 – 0.040[1,2]	0.035
Wetland	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with water.	0.035 – 0.140[1,2]	0.050
Developed - Low	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover.	0.050 – 0.110[1,2]	0.055
Shrub (1D)	Areas dominated by shrubs; less than 5 m tall with shrub canopy greater than 20% of total vegetation.	0.070 – 0.160[3]	0.060
Shrub (2D)		0.050 – 0.140[1,2]	0.050
Tree (1D)	Areas dominated by trees generally greater than 5 m tall. Neither deciduous nor evergreen species are greater than 75% of total tree cover	0.080 – 0.200[3]	0.070
Tree (2D)		0.060 – 0.180[1,2]	0.060

1. Hydrologic Engineering Center (2025b)
2. Arcement, G.J, and Schneider, V.R (1989)
3. Chow, V. Te. (1959)

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Solver: The HEC-RAS 2D User's Manual (Hydrologic Engineering Center, 2025b) recommends using the Shallow Water Equations (SWE) over the Diffusion Wave Equations (DWE) for river systems with very flat slopes (<0.0002 m/m) as gravity and friction forces are less dominant for water movement and acceleration terms for flood waves become increasingly important. The estimated Peace River bed slope within the lower reach is almost one order of magnitude lower than this reference value. Therefore, the Shallow-Water Equations (SWE) were adopted for this study instead of the default Diffusion Wave Equations.

Computation time steps: The model computation time step was set to 10 seconds. Stable solutions were found with the adopted time step. Hydrograph and mapping outputs were set to 30 minutes.

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Simulation time and quasi-steady flow assumption: A constant inflow time series was applied over an extended simulation period to achieve a quasi-steady state condition where constant water levels remain throughout the computational domain by the end of the simulation period. A six-day simulation period provided constant water levels throughout the computational domain by the end of this period for all but the smaller magnitude floods (i.e. 1:2 to 1:10 floods) where, water levels continued to rise very gradually at rates of a few millimeters per day. The simulation period was extended to twelve days for these smaller magnitude floods to achieve a quasi-steady state condition by the end of the simulation period.

The quasi-steady state condition was evaluated for each 2D cell throughout the entire computational domain by calculating the difference in water level values over the final 2 hours of simulation time. The calculated changes in water levels over the entire domain were less than 0.01 m for all simulations confirming that water levels had stabilized by the end of the simulation period.

4.3.5 Open Water Flood Frequency Profiles

The hydraulic model was used to generate flood frequency profiles for the thirteen open water floods of varying magnitude listed in **Table 3-1**. The computed flood frequency water levels are listed in **Appendix H** and depicted graphically on **Figure 11** and **Figure 12** for the Peace River and Garden Creek, respectively.

4.3.6 Model Sensitivity

A model sensitivity analysis was conducted to evaluate the impacts of adjusting key model parameters on water surface elevations, flow depths and inundation widths. The analysis was based on the 1:100 open water design flood, which served as the baseline condition. Model parameter variations included adjustments to discharge, the downstream boundary condition, and Manning's roughness values.

The incremental changes in water surface elevations and flood depths are identical. For this sensitivity analysis, water surface elevations were selected as the comparison metric since they are easier to visualize through the comparison of water surface profiles. The water surface elevation variances for the Peace River were extracted at each 1D cross section while for Garden Creek is based on data extracted at 100 m intervals along its river centreline.

Inundation widths for the baseline and sensitivity test conditions were visually compared. Differences from the baseline scenario were examined along defined river sections. For the Peace River three sets of sections were evaluated: river kilometer 0 to 10.5 and 11.5 to 47, and river kilometer 10.5 to 11.5. For Garden Creek three sections were assessed: downstream (below) of the Hwy 58 bridge, Hwy 58 bridge to river kilometer 15, and upstream (above) of river kilometer 15.

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Sensitivity to Variation in Discharge

To assess the impact of discharge uncertainty, the lower and upper limits of the 95% confidence interval for the 1:100 open water design flood of the Peace River and Garden Creek were simulated in the model. The lower flood frequency estimate scenario used discharge estimates of 16,700 m^3/s for the Peace River and 92.4 m^3/s for Garden Creek. The higher flood frequency estimate scenario used discharge estimates of 20,300 m^3/s for the Peace River and 123 m^3/s for Garden Creek.

Table 4-4 shows variations in the water surface elevations for the adjusted flood frequency estimates from the 1:100 open water flood baseline condition. **Figure 13** and **Figure 14** show a comparison of the baseline and sensitivity test water surface profiles for both the Peace River and Garden Creek, respectively.

Table 4-4 Water surface elevation sensitivity to varied discharges

Reach	Variance from 1:100 open water design flood baseline condition (m)			
	Lower limit flood frequency estimates		Upper limit flood frequency estimates	
	Mean	Maximum	Mean	Maximum
Peace River	-0.38	-0.43	0.46	0.50
Garden Creek	-0.24	-0.36	0.32	0.45

Table 4-5 summarizes flood inundation width differences for the adjusted flood frequency estimates from the 1:100 open water design flood baseline condition.

Table 4-5 Flood inundation width sensitivity to varied discharges

Reach	Range of variance from 1:100 open water design flood baseline condition	
	Lower limit flood frequency estimates	Upper limit flood frequency estimates
Peace River		
River kilometer 0 to 10.5 and 11.5 to 47	Less than -1 m to -150 m	Less than 1 m to 25 m
River kilometer 10.5 to 11.5	-2 m to -120 m	200 m to 500 m
Garden Creek		
Below Hwy 58	Less than -1 m to -150 m	Less than 1 m to 150 m
Hwy 58 to river kilometer 15	Less than -1 m to -80 m	Less than 1 m to 140 m
Above river kilometer 15	Less than -1 m to -15 m	Less than 1 m to 15 m

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The lower and upper limit flood frequency estimates slightly change flood inundation widths along the Peace River with the largest variations between river kilometers 10.5 to 11.5, 22 to 25, 28 to 31, and 38.

Adjusting the flood frequency estimates for Garden Creek produces larger percentage changes in flood inundation width than those observed on the Peace River. Key sections of variations are observed near river kilometers 1, 3, and 9 to 10.

Sensitivity to Variation in Downstream Boundary Condition

A sensitivity analysis was completed to assess the impacts of varying the downstream boundary conditions for the model. The model includes three downstream boundaries: the left overbank area (2D), the Peace River main channel (1D), and the right overbank area (2D).

To evaluate the uncertainty in this approximation a sensitivity analysis was completed by prescribing varied channel rating curves to the coupled 1D/2D model. These rating curves were derived from supplementary 1D HEC-RAS modelling of the extended Peace River reach (described in **Section 4.3.1.8**), where the slope of the normal depth downstream boundary approximation was varied by ±20%.

For each sensitivity test, the slope of the normal depth downstream boundary approximation of the left and right 2D overbank areas were also varied by ±20%. The reduced slope scenario adopted a normal depth downstream boundary approximation slope of 0.000028 m/m while the increased slope scenario adopted a value of 0.000042 m/m.

Table 4-6 summarizes the resulting changes in water surface elevations from the 1:100 open water design flood baseline condition due to summarized changes in the downstream boundary.

The Peace River through the study area is very flat (~ 0.000035 m/m in the lower reach) and computed water levels were found to be sensitive to changes in the downstream boundary along the entirety of the modelled Peace River reach. Garden Creek is comparatively much steeper and the sensitivity of computed water levels to changes was limited to the downstream reach near the boundary. **Figure 15** and **Figure 16** illustrate the resulting water surface profiles compared to the baseline conditions for the Peace River and Garden Creek, respectively.

Table 4-6 Water surface elevation sensitivity to varied downstream boundary condition

Reach	Variance from 1:100 open water flood baseline condition (m)			
	Reduced normal depth downstream boundary approximation		Increased normal depth downstream boundary approximation	
	Mean	Maximum	Mean	Maximum
Peace River	0.29	0.42	-0.21	-0.33
Garden Creek	0.14	0.26	-0.09	-0.19

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Table 4-7 lists the observed changes in flood inundation widths from the 1:100 open water design flood baseline condition due to changes in the prescribed slope of the normal depth approximation downstream boundary.

Table 4-7 Flood inundation width sensitivity to varied downstream boundary condition

Reach	Range of variance from 1:100 open water design flood baseline condition	
	Reduced normal depth downstream boundary approximation	Increased normal depth downstream boundary approximation
Peace River		
River kilometer 0 to 10.5 and 11.5 to 47	Less than 1 m to 40 m	Less than -1 m to -90 m
River kilometer 10.5 to 11.5	250 m to 470 m	Less than -1 m to -100 m
Garden Creek		
Below Hwy 58	Less than 1 m to 80 m	Less than -1 m to -70 m
Hwy 58 to river kilometer 15	Less than 1 m to 25 m	Less than -1 m to -30 m
Above river kilometer 15	Imperceptible at mapping scale	Imperceptible at mapping scale

Similar to the discharge sensitivity tests the most notable changes in inundation widths along the Peace River occur between river kilometers 10.5 to 11.5, 22 to 25, 28 to 31, and 38; and, 1, 3, and 9 to 10 along Garden Creek. Boundary condition adjustments result in larger percentage changes flood inundation widths along Garden Creek compared to Peace River, relative to each reach's respective baseline inundation width.

Sensitivity to Variation in Channel Roughness

To evaluate the impact of Manning's roughness values in the main channels on hydraulic results, the roughness values were adjusted by ± 20%. The original values assigned were 0.026 for the Peace River and the Peace River side channel, and 0.040 for Garden Creek. **Table 4-8** summarizes the adjusted main channel roughness values used in the sensitivity tests.

Table 4-8 Varied main channel roughness values

Reach	Manning's roughness coefficient		
	Baseline condition	Reduced main channel roughness values	Increased main channel roughness values
Peace River	0.026	0.021	0.031
Garden Creek	0.040	0.032	0.048
Peace River side channel	0.026	0.021	0.031

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Table 4-9 presents the variation in water surface elevations with the varied channel roughness values from the 1:100 open water design flood baseline scenario. **Figure 17** and **Figure 18** illustrate the resulting sensitivity test profiles in comparison to the 1:100 open water design flood baseline profile for the Peace River and Garden Creek, respectively.

Table 4-9 Water surface elevation sensitivity to varied channel roughness values

Reach	Variance from 1:100 open water design flood baseline condition (m)			
	Reduced main channel roughness values		Increased main channel roughness values	
	Mean	Maximum	Mean	Maximum
Peace River	-0.14	-0.37	0.12	0.34
Garden Creek	-0.08	-0.16	0.08	0.13

Table 4-10 lists the resulting variations in flood inundation widths due to varied channel roughness values from the 1:100 open water flood baseline scenario.

Table 4-10 Flood inundation width sensitivity to varied channel roughness values

Reach	Range of variance from 1:100 open water design flood baseline condition	
	Reduced main channel roughness values	Increased main channel roughness values
Peace River		
River kilometer 0 to 10.5 and 11.5 to 47	Less than -1 m to -25 m	Less than 1 m to 25 m
River kilometer 10.5 to 11.5	Less than -1 m to -10 m	Less than 1 m to 12 m
Garden Creek		
Below Hwy 58	Less than -1 m to -30 m	Less than 1 m to 20 m
Hwy 58 to river kilometer 15	Less than -1 m to -10 m	Less than 1 m to 10 m
Above river kilometer 15	Imperceptible at mapping scale	Imperceptible at mapping scale

Adjusting the channel roughness does not result in significant changes to the flood inundation widths along the Peace River compared to the previous sensitivity tests (adjustments to discharge estimate and downstream boundary condition).

Sensitivity to Variation in Overbank Roughness

The open water calibrations were limited to events confined within the Peace River, Peace River side channel, and Garden Creek. Although the assigned overbank roughness values remained within the recommended range of values outlined by National Land Cover Database, the range is quite large indicating a high degree of variability. To evaluate the potential impact of this

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uncertainty the overbank roughness values in the 1D domain and for all land cover types in the 2D domain were varied by ± 20%. **Table 4-11** provides a summary of the varied overbank roughness values with reference to the baseline condition values.

Table 4-11 Varied overbank roughness coefficients

Overbank type	Manning's roughness coefficient		
	Baseline condition	Reduced overbank roughness values	Increased overbank roughness values
Shrubs (1D)	0.060	0.048	0.072
Trees (1D)	0.070	0.056	0.084
Open water (2D)	0.035	0.028	0.042
Wetland (2D)	0.050	0.040	0.060
Developed - Low Density (2D)	0.055	0.044	0.066
Shrub (2D)	0.050	0.040	0.060
Tree (2D)	0.060	0.048	0.072

Table 4-12 presents the resulting variation in water surface elevations under both the reduced and increased overbank roughness scenarios from the 1:100 open water design flood baseline condition. **Figure 19** and **Figure 20** compare the sensitivity test profiles under both scenarios to the baseline profile for the Peace River and Garden Creek, respectively.

Table 4-12 Water surface elevation sensitivity to varied overbank roughness values

Reach	Variance from 1:100 open water design flood baseline condition (m)			
	Reduced overbank roughness values		Increased overbank roughness values	
	Mean	Maximum	Mean	Maximum
Peace River	-0.30	-0.33	0.24	0.26
Garden Creek	-0.20	-0.30	0.18	0.25

Table 4-13 summarizes changes in flood inundation widths from varied overbank roughness values from the 1:100 open water design flood baseline scenario.

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Table 4-13 Flood inundation width sensitivity to varied channel roughness values

Reach	Range of variance from 1:100 open water design flood baseline condition	
	Reduced overbank roughness values	Increased overbank roughness values
Peace River		
River kilometer 0 to 10.5 and 11.5 to 47	Less than -1 m to -80 m	Less than 1 m to 40 m
River kilometer 10.5 to 11.5	Less than -1 m to -100 m	Less than 1 m to 470 m
Garden Creek		
Below Hwy 58	Less than -1 m to -100 m	Less than 1 m to 90 m
Hwy 58 to river kilometer 15	Less than -1 m to -60 m	Less than 1 m to 50 m
Above river kilometer 15	Less than -1 m to -10 m	Less than 1 m to 10 m

The greatest sensitivity to inundation widths from the varied overbank roughness values along the Peace River and Garden Creek were consistent to the discharge and downstream boundary condition sensitivity tests.

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5 ICE JAM MODELLING

5.1 Available Data

Several data sources including ice jam highwater marks; information from ice observation reports and other documentation; and gauge data and rating curve information were collected. This data was used to characterize the river ice regime, document flood history and develop the methodology for estimating ice jam flood frequencies.

5.1.1 Ice Jam Highwater Marks

Highwater marks (HWMs) are physical indicators representing the maximum water elevation attended over the duration of a flood event. They are usually identified, documented, and surveyed after the flood event. Ideally, they are collected soon after flood waters recede. In some cases, evidence of HWMs persist for years and can be identified long after the passing flood; however, these data are less reliable and their associated highwater event is uncertain.

These marks are typically formed by floodwaters and may appear as lines, marks, or deposits on structures, terrain, or vegetation. They are often identified through natural evidence, such as water staining, debris lines or piles, soil discoloration, or vegetation damage. Multiple piles of woody debris were evident during the field survey program. Several of these were surveyed as they were considered to be indicative of highwater.

Several ice scars were found and documented during this survey – most of which were located on Garden Creek close to the mouth. Ice scars are physical marks or damage on trees or other riparian vegetation caused by the impact of moving ice. These scars provide an estimate of the elevation of the ice where it impacted/scarred the trees. Interpretation of these scars can be challenging, as multiple scarring may be experienced by single tree over a single event or multiple events from different years. Ice scars can overestimate highwater levels by several meters when ice floes are pushed up banks impacting trees meters above the water surface.

Instances of highwater were identified in ground and aerial photographs. Highwater elevations were estimated from these photos by approximating the location of the flood extent, depicted in the photo, on the georeferenced aerial image and then extracting the ground elevation from the project DTM, at that location. Highwater marks were estimated in this manner from oblique aerial photos taken from aircraft during the 1996 and 2020 ice jam flood events. The photos used for these highwater estimates are illustrated in **Figure 21**. A summary of the ice jam highwater elevation information collected for this study are listed in **Table 5-1**.

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Table 5-1 Summary of ice jam flood highwater marks

River	Approximate Model River Station (m)	Approximate River KM	Event Date	Highwater Mark Elevation (m)	Category
Peace River	40670	2.2	UNKNOWN	230.89	Tree Scar – NHC 2025 Survey
Peace River	62830	24.4	UNKNOWN	232.93	Tree Scar – NHC 2025 Survey
Peace River	67970	29.5	UNKNOWN	232.25	Debris Pile – NHC 2025 Survey
Peace River	67970	29.5	UNKNOWN	229.28	Debris Pile – NHC 2025 Survey
Peace River	69870	31.4	26 April 1996	231.60	Highwater from oblique aerial photograph
Peace River	70070	31.6	30 April 2020	235.60	Highwater from oblique aerial photograph
Garden Creek	380	0.4	UNKNOWN	231.22	Tree Scar – NHC 2025 Survey
Garden Creek	490	0.5	UNKNOWN	230.95	Tree Scar – NHC 2025 Survey
Garden Creek	400	0.4	UNKNOWN	230.63	Tree Scar – NHC 2025 Survey
Garden Creek	1060	1.1	UNKNOWN	230.11	Tree Scar – NHC 2025 Survey
Garden Creek	1010	1.0	2018	233.90	Highwater from site photograph
Garden Creek	1010	1.0	30 April 2020	235.40	Highwater from oblique aerial photograph

5.1.2 Ice Observation Reports and Other Documentation

Ice Observation Reports

Ice observation reports are produced annually by Environment and Protected Areas (EPA), formerly Alberta Environment and Parks (AEP) and Alberta Environment (AENV), documenting ice conditions along the Peace River from the W.A.C. Bennett Dam to the Peace-Athabasca Delta. These reports primarily focus on ice progression in the upper reaches of the Peace River. Ice observation reports for the Town of Fort Vermilion extend over 25 years, covering the periods 1974–1975, 1981–1985, and 2004–2019 (NHC, 2022).

Documentation specific to Garden River is sparse, with observational accounts limited to the 2018, 2019, 2020, 2021, and 2024 breakup events. These reports provide a record of the date and type of ice breakup and include a summary of the sequence of events observed at Fort Vermilion, Garden River, and Peace Point.

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Canadian River Ice Database (CRID)- Online Resources

The Canadian River Ice Database (CRID) was established by the Water Science and Technology Directorate of Environment and Climate Change Canada as a long-term initiative to compile, archive, and analyze river ice data derived from hydrometric records. The dataset is accessible online via the ECCC Data Catalogue (Canadian River Ice Database - ECCC Data Catalogue). CRID provides time series for up to 15 river ice variables at each station, including freeze-up and breakup events, winter low levels, ice thickness, and peak open-water levels. Comprehensive details on the program and its associated data are provided by de Rham et al. (2020).

CRID data is available for select stations which included the WSC Gauge 07KC001 (Peace River at Peace Point). The CRID database does not include WSC Gauge 07HF001 (Peace River at Fort Vermilion).

Canadian River Ice Database (CRID)- Supplemental Data

In addition to the information available in the online CRID Database, the dataset was recently extended by Laurent de Rham for stations within the Mackenzie River Basin, including Peace Point. The extended dataset (2016–2023) was provided to NHC for this study.

These supplementary materials, including flow charts, WSC ice survey field notes, and gauge notes, were used to supplement the CRID dataset available online. The compiled dataset includes information for both the freeze-up and breakup periods.

The online and supplementary CRID data WSC Gauge 07KC001 (Peace River at Peace Point) primarily consist of information related to freeze-up and breakup periods. Breakup-related data in the CRID database for Peace Point—including spring breakup initiation and peak water levels, along with the corresponding discharges—were extracted and analyzed to supplement the continuous daily hydrometric dataset and to support the assessment of the timing and severity of breakup events. In summary, the CRID database contains 57 years of records for WSC Gauge 07KC001 (Peace River at Peace Point), spanning the period 1959–2016. Within this record, peak breakup data are available for 47 years, while the 1971–1972 and 1998–1999 periods include only water level information, with no corresponding discharge or timing data.

Alberta Highway Information System (HIS) Flood Documentation

The Alberta Highway Information System (AHIS), maintained by Alberta Transportation and Economic Corridors, contains records of documented floods at bridge locations across the province. For this study, there are two bridge crossings along the Garden Creek. The Alberta HIS dataset does not include information for these crossings.

Previous Flood Study

A prior flood study on the Peace River at Fort Vermilion was completed by NHC (2022). This study compiled and documented relevant information for ice jam modeling and analysis at Fort

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Vermilion. This information was included in the ice jam flood frequency analysis. There were no prior Provincial flood studies completed for the Peace River or Garden Creek at Garden River.

5.1.3 Gauge Data

Water level and discharge data for the breakup period was inspected for several WSC gauges along the Peace River. The Peace River at Fifth Meridian gauge is the only WSC gauge located near the study area. However, it only contains discharge data for the summer months between 1960 and 1967 and thus is not adequate for use in this study. As no relevant gauge data exists in the study area, the gauge records examined for this study were obtained from the nearest WSC gauges located upstream and downstream of Garden River: Peace River at Fort Vermilion (approximately 150 km upstream) and Peace River at Peace Point (approximately 120 km downstream).

The gauge data included water level and discharge records for periods prior to 2011, current and historical rating curves, direct measurement data used to establish the rating curves, and gauge information sheets, all of which were incorporated into the analysis. **Table 5-2** summarizes the WSC gauges and associated hydrometric information collected and compiled for this study.

Table 5-2 Hydrometric recordings and supplementary data availability for WSC stations

Station ID-Name	Station Data Range	Supplementary Data Range
07HF001-PEACE RIVER AT FORT VERMILION	- Level: 1979-1993, 2012-2025 [29 years] - Continuous Level: 2011-2024 [14 years] - Discharge: 1915-1922, 1960-1978,1979-1993[1], 2006-2025 [62 year] - Continuous Discharge: 2011-2024 [14 years]	- Continuous Level: 2006-2010 [5 years] - Continuous Discharge: 2006-2010 [5 years] - Direct Measurements - Current and historical rating curves (5 total) - Gauge Benchmark History
07KC001-PEACE RIVER AT PEACE POINT	- Level: 2002-2025 [14 years] - Continuous Level: 2011-2024 [14 years] - Discharge: 1959-2025 [67 years] - Continuous Discharge: 2011-2024 [14 years]	- Continuous Level: 1996-2010 [15 years] - Continuous Discharge: 1996-2010 [15 years] - Direct Measurements - Current and historical rating curves (4 total) - Gauge Benchmark History
07KA002-PEACE RIVER AT FIFTH MERIDIAN	- Discharge: 1960-1967 [6 years]	No Data Available

Note:
1. Discharge data had been synthesized for 1979-1993 from the recorded water levels using the 1979 rating curve.

Hydrometric records for station 07HF001 span the period from 1917 to 2023, with the majority of the dataset (1917–2018) compiled and analyzed in the Fort Vermilion Flood Hazard Study conducted by NHC in 2020 (NHC 2022). This dataset is subsequently extended in this study by

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an additional five years (2019–2023) using data that became available thereafter. Using the gauge records and supplemental data sources, a comprehensive dataset was compiled for the Town of Fort Vermilion, including daily and continuous water levels, covering the full period of record.

Hydrometric records from WSC station 07KC001 at Peace Point were compiled and analyzed to provide insights into flood conditions in the study area, in conjunction with the data prepared for the upstream station 07HF001 (Peace River at Fort Vermilion).

5.2 Model Construction

The basic inputs required by the ice model are much the same as those required by an open water model (i.e., river cross sections along known lengths of channel, roughness coefficients for the channel and overbank areas at each cross section, a specified or computed water level at the downstream model boundary, and a discharge at all upstream model boundaries). In addition to these basic inputs, the ice model requires at each model cross section: a prescribed ice cover condition, under ice roughness, and a set of ice jam parameters characterizing the properties of the ice jam. These ice model inputs are used to solve for the under-ice hydraulics and ice jam stability relationship.

The ice model adopted for this study is a 1D model which was created through enhancement of the open water model to provide a good analogue of ice affected flood profiles along the main channel of the Peace River study reach. Details of the enhancement methodology follow below.

5.2.1 Ice Model Enhancement Methodology

The primary purpose of the ice model was to develop a family of ice affected flood profiles over a range of breakup ice conditions. Together these profiles provided breakup rating curves that were used by the ice jam frequency analysis (described further below in section 5.2.3). The ice model was enhanced to simulate three breakup types which represent the range of ice affected flood conditions anticipated at the study site; that is, a thermal breakup, a mechanical breakup with an ice run, and a mechanical breakup with a fully developed ice jam. Specifics on the enhancements adopted for each of these breakup types is included in the sections that follow.

5.2.1.1 Enhancement for 1D Open Water Approximation

The open water model is a coupled 1D / 2D model with a 1D geometry for the main Peace River channel coupled to 2D model representing Garden Creek, side channels, and all overbank areas. The HEC-RAS model does not provide an option to run 2D simulations for ice conditions – ice conditions can only be modelled with a 1D geometry.

The first step in ice model enhancement was to create a 1D open water approximation of the calibrated 1D / 2D open water model. The resulting 1D open water approximation produced

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open water profiles that agreed with those computed by the 1D / 2D open water model, as depicted in **Figure 22**. The methodology for creation of the 1D open water approximation model was to extend the 1D main channel geometry (from the open water model) into the overbank / floodplain by the following steps.

1. Extend 1D main channel into overbank areas across the entire flood plain. Alignment of the sections were informed by inspection of the overland flow pattern visualized in the open water model.
2. Assign roughness values in overbank areas. Roughness values in main channel were the same as for the open water 1D main channel and roughness values in the overbank areas were initially set to values approximately equal to a composite roughness of the values used in the 2D open water model, along the extended overbank section.
3. Compute and compare calculated open water flood frequency profiles to those computed by the open water model. Adjust flow areas and roughness in the overbanks to improve the fit to the open water flood frequency profiles. Adjustments to roughness were applied to raise or lower water levels along a segment of the reach. Flow area adjustments (created by introducing blocked obstructions) provided more localized changes in water levels. Introducing blocked obstructions also helped to account for ineffective flow regions.
4. Check and compare computed discharge in the main channel portion of the 1D open water approximation model to the 1D open water model. Make slight adjustments to the blocked obstructions to better match flows within in the main channel.
5. Iterate through the above process until the 1D open water approximation calculated water levels to within 5 cm, on average, and no more than ~10 cm, to the open water model, over the full range of open water flood frequencies.
6. Check and ensure the computed discharge in the main channel was within 25% of the open water main channel (1D section).

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It was not technically feasible to fully match discharges along the main channel. Nevertheless, the 1D approximation provided a good analogue of the open water with respect to water levels and a reasonable approximation of the flows within the main channel where ice jam stability relationships were applied in the model. Further enhancements to the ice model were built from this 1D open water approximation model geometry.

5.2.1.2 Geometry Improvements

The basic geometry inputs required by the enhanced ice model include those required by the HEC-RAS open water model. In addition to these basic inputs, the enhanced model requires at each model cross section: a prescribed ice cover condition; under ice roughness; and a set of ice jam parameters characterizing the properties of the ice jam. These ice enhanced model inputs are used to solve for the under ice hydraulics and ice jam stability relationship.

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Main channel widths: The ice jam profile computations can be sensitive to abrupt changes in the channel width. Adjustments were made so that the modelled main channel (portion between left bank and right bank stations) was representative of an average ice jam width along the river and also to ensure changes in the ice jam width were gradual. The location of bank stations also represents the estimated location of shear walls left alongside river banks after the passing of the ice jam or ice run. In the case of islands or a split, banks were set for a single side of the island – typically the wider side channel that transitions well from the upstream to downstream main channel. This assumes the ice jam develops along one side of the channel and then develops or fills in the other side. Setting banks to include the island and both channels would overestimate the accumulation width parameter used in the jam stability relationship (refer to Equation [1]).

Bed roughness: The bed roughness was set to the same values as was used in the open water model.

Ineffective flow areas: There were no ineffective flow areas in the open water model and ineffective flow areas were not introduced in the ice jam model.

Levees: There were no levees in the open water model and levees were not introduced in the ice jam model.

Overbank extents: The main channel sections were extended into the overbank areas as to allow flows from the main channel (where ice jams are simulated) to overtop the banks as ice-affected flood levels surpass the banks of the main channel. The method for creating the overbank extents is provided in the previous section describing the enhancement for 1D open water model approximation (**Section 5.2.1.1**).

Blocked obstructions: Further adjustments were made to the overbank extents by introducing blocked obstructions to adjust flows in the main channel and overbank areas. Adjustments were made until computed water levels (and discharge in the main channel) well-approximated the 1D portion of the 1D / 2D coupled open water model (as described, previously, in **Section 5.2.1.1**).

Overbank roughness: Overbank roughness values were adjusted to improve the 1D ice jam model's ability to well-approximate open water flood profiles computed by the 1D / 2D coupled open water model (as described, previously, in **Section 5.2.1.1)**. Composite roughness values in the overbanks ranged from about 0.045 to 0.065 (comparable to the range of values used for the open water model, **Table 4-3**).

5.2.1.3 Enhancements Specific to Ice Conditions or Breakup Type

The HEC-RAS model allows the user to specify the ice cover condition as an option within the HEC-RAS cross section data editor. If no information is provided for the ice cover, then an open water condition is presumed. If the user assigns a value to the ice cover thickness, then the

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model applies an ice cover condition. When an ice cover condition is defined, the user must provide the following:

- Ice cover thickness in left overbank, main channel, and right overbank.
- Ice cover roughness values for the left overbank, main channel, and right overbank.
- Ice cover specific gravity.
- Ice cover condition (*known* geometry or *wide-river* ice jam).
- If ice cover condition is set to *wide-river* ice jam; ice jam strength parameters (internal friction, ice jam porosity, stress ratio constants, maximum under ice velocity).
- Option to use a fixed or variable ice cover roughness.

Additional detail on these parameters and how the model was enhanced for the various ice covered conditions is provided in the following sections. The model enhancements were only applied to the Peace River. Ice processes were not simulated for Garden Creek; the flood levels estimated on Garden Creek for ice-affected flood conditions were based on backwater from ice-affected water levels on the Peace River.

Thermal Breakup

Thermal breakup describes a breakup condition dominated by thermal processes. Breakup is characterized as uneventful and flood levels are typically low. A thermal breakup condition was prescribed in the model by selecting the known geometry option and ascribing a constant ice thickness along the full study reach. The constant ice thickness was assumed to be a pre-breakup ice thickness. A value of 0.75 m was adopted as the pre-breakup ice thickness for all thermal breakup ice cover conditions. This thickness was estimated as the average of late winter ice thickness measurements reported by WSC at the Fort Vermillion and Peace Point gauges. There was no data available to calibrate the under ice roughness. The pre-breakup cover is expected to be hydraulically smoothed over the winter period and an under ice Mannings roughness value of 0.01 was adopted. This is the middle of the range of values recommended in the HEC-RAS Hydraulic Reference Manual for smooth ice (Hydrologic Engineering Center, 2020).

The HEC-RAS model allows the user to specify the ice cover condition as either, a “known geometry” or a “wide-river” ice jam. For a known geometry condition, the user prescribes the ice thickness at each cross section along with a corresponding underside ice roughness (denoted in the model as Ice Cover Manning’s n Values). The known geometry option was specified for the thermal breakup model geometry.

Mechanical Breakup resulting in an Ice Jam

A mechanical breakup resulting in an ice jam describes the condition where breakup is dominated by mechanical processes where broken ice mobilizes and *runs* downstream. When the running ice is arrested it accumulates and thickens to form an ice jam. The option to compute an (wide-river) ice jam profile was set in the ice cover editor for the mechanical

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breakup resulting in an ice jam scenario. When the ice jam option is selected, the model requires additional parameters to characterize the strength properties of the ice jam accumulation, as follows.

HEC-RAS uses the following form of the ice jam stability equation (for the wide-river ice jam condition) to characterize the strength of the accumulation. It is a force balance equation where the stresses acting on the jam are ultimately transmitted to the channel banks (Hydrologic Engineering Center, 2020).

$$\frac{d(\bar{\sigma}_x t)}{dx} + \frac{2\tau_b t}{B} = \rho' g S_w t + \tau_i \qquad [1]$$

Where:

$\bar{\sigma}_x$ = the longitudinal stress (along stream direction)

t = the accumulation thickness

τ_b = the shear resistance of the banks

B = the accumulation width

ρ' = the ice density

g = the acceleration of gravity

S_w = the water surface slope

τ_i = the shear stress applied to the underside of the ice by the flowing water

The ice jam stability equation can be restated in the following form which includes the ice jam parameters required by the model.

$$\frac{dt}{dx} = \frac{1}{2k_x\gamma_e}\left[\rho' g S_w + \frac{\tau_i}{t}\right]] - \frac{k_o k_1}{B} t \qquad [2]$$

Where:

t = the accumulation thickness

k_x = a coefficient describing the ratio of vertical to longitudinal stress

γ_e = the effective unit weight of the accumulation

ρ' = the ice density

g = the acceleration of gravity

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S_w = the water surface slope

τ_i = the shear stress applied by the flow to the underside the accumulation

B = the accumulation width

k_o = a coefficient describing the ratio of longitudinal to transverse stress

k_1 = a coefficient describing the ratio of transverse stress to shear at the banks

HEC-RAS uses an iterative approach to compute the ice jam profile thickness and under ice hydraulics. The under ice hydraulics are solved in a manner akin to the standard step method where the solution progresses in the upstream direction, then the ice jam thickness is found by solving the jam force balance equation (progressing in a downstream direction). The process is repeated until the user specified tolerances for changes in computed water levels are achieved or the maximum number of iterations is exceeded. The ice jam model simulations stayed below the maximum number of iterations for all ice jam scenarios.

Composite Roughness, n_o: The composite ice roughness is the combined bed and ice roughness factor resisting flow under the ice cover. HEC RAS first computes the composite roughness, n_o, following the familiar Sabeneev relationship as follows:

$$n_o = \left(\frac{n_{bed}^{3/2} + n_{ice}^{3/2}}{2}\right)^{2/3} \qquad [3]$$

where n_{bed} and n_{ice} are the bed and bottom of ice roughness values, respectively.

Jam Stability Parameters

The jam stability parameters required as input to the HEC RAS model to solve Equation [2] include: the internal friction angle of the jam, ϕ; the ice jam porosity (fraction of voids between ice floes), p; and the coefficient of lateral to longitudinal stress in the jam, k_1. All other parameters are solved internally by the model. Ice jam strength properties can not be measured directly in the field and consequently they are not reported for observed events. However, for an idealized *equilibrium* thickness condition, the suite of jam stability parameters can be lumped into a single *jam stability* parameter, commonly denoted as μ which can be expressed as:

$$\mu = \tan\phi\,(1-p)\tan^2(45 + \phi/2)k_1\,(1-p) \qquad [4]$$

with

$$k_x = \tan^2(45 + \phi/2) \qquad [5]$$

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With these relationships it was possible to estimate the required input parameters ϕ and k_1, given the more familiar jam stability parameters μ and p. Also, to compare k_x to values reported in the literature.

Ice Jam Porosity: Ice jam porosity represents the volume fraction of the interstitial spaces in the ice accumulation. It is assumed to be the same above and below the water surface. A value of p = 0.4 is the HEC-RAS default and was used for this study. This value was also used for the nearest flood study completed on the Peace River at Fort Vermilion (Northwest Hydraulic Consultants, 2022).

Jam Stability Parameter: Previous investigators have estimated μ to be in the range of 0.8 to 2.0 for the Peace River at TPR, with the larger values being associated with smaller ice jams (Andres 1996). Neil and Andres (1984) reported an estimated value of 0.93 for a large 1982 ice jam near TPR. A value of μ = 1.0 was adopted for Fort Vermilion Flood Study (Northwest Hydraulic Consultants, 2022). Inspection of the oblique aerial images of events depicted a wide range of ice floe dimensions from small to very large with "slushy" material in between. The ice jam accumulations for this study were considered to have an internal strength that was tending toward the lower range and so a value of μ = 0.8 was selected for this study.

Internal Friction and Coefficient of Lateral to Longitudinal Stress: The internal friction and stress coefficient were found by substitution of the adopted values for p = 0.4, μ = 0.8, k_x = 12 into equations [4] and [5] resulting in adopted values of ϕ = 58° and k_1 = 0.069. This provides for values which falls within the range of values deduced from field experience as reported by Beltaos (2008) and White (1999).

Mechanical Breakup resulting in an Ice Run

The final ice condition was denoted as a mechanical breakup resulting in an ice run. For a given discharge, this condition results in water surface elevations that are greater than a thermal breakup condition and lesser than a fully developed ice jam condition. This ice condition may also be indicative of other "in-between" ice conditions such as partial jams or backwater from a jam some distance downstream. HEC-RAS does not have the capability to simulate dynamic ice run conditions and there are no other practical tools available for direct estimation of such conditions.

The ice run condition for this study was approximated by adding the estimated submerged thickness portion of a fully developed ice jam atop of an open water flood depth corresponding to the same discharge. The rational for this approximation is that during a mechanical breakup, the ice rubble will shove and accumulate somewhere upstream of the gauge and that some portion of the accumulation will achieve a fully developed ice jam thickness. When the upstream accumulation releases, a surge of water and ice "runs" downstream. The peak water level associated with the ice run is approximated by the open water rating curve elevation plus the submerged thickness of the ice run.

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The ice run thicknesses were estimated from ice jam thicknesses calculated by the fully developed ice jam model within the upper portion of the study reach, where the reach geometry was considered more representative of conditions upstream of the study reach. The incremental rise in water level associated with the ice run was simulated in the model with the *known geometry* option (same as that used for thermal breakup). The underside ice roughness was set to zero such that the "running" ice added negligible resistance to flow and the incremental rise in water levels is attributed to the submerged thickness of the running ice.

5.2.2 Ice Jam Model Calibration

Ice jam calibration was based on very limited information found for the 2018 and 2020 breakup events (refer to **Table 5-1**, **Figure 21**). In spite of the limited data, the resulting ice jam model provided adequate elevation – discharge relationships (rating curves) that were required by the ice jam flood frequency analysis (refer to **Section 5.2.3**).

2020 Breakup Ice Jam

The 2020 breakup was a severe breakup event. The unnamed bridge in Garden River was overtopped by backwater from the ice jam in Peace River (refer to **Figure 21**). The highwater elevation at the bridge were estimated by comparison of waters edge depicted in the photo to elevations in the project DTM at the same location. Based on this, the flood level were estimated to be about 235.4 m to 235.6 m. The under ice roughness of was adjusted to provide flood levels at the mouth of Garden Creek that approximated this elevation. An under ice roughness value, n_{ice} = 0.05 resulted in a computed water level near Garden River of 235.55 m which well approximated this flood elevation. Visual inspection of the flood extents generated by the model (viewed within RASMapper) agreed well with the flood extents depicted in the photo. A plot of the calibrated ice jam profile compared to highwater elevations is provided in **Figure 23**. Surveyed elevations of ice tree scars and debris piles found during the field program are included for comparison. The indicate highwater from historic events but the years for which these scars and piles were formed were not determined under this study. The 1996 ice jam highwater elevation is also included for comparison. There were no reliable discharge estimates for the 1996 event so it was not possible to calibrate or validate the model against this additional information. The additional highwater information depicted on **Figure 23** is listed in **Table 5-1**.

2018 Breakup Ice Run

Information was available for the 2018 breakup including a report on the sequence of breakup along the Peace River (Jasek, 2019) and observations by NHC staff who happened to be in the area during the 2018 ice run. **Figure 24** provides a comparison between measured flood levels published by Jasek (2019) and **Figure 25** illustrates the flood levels computed by the calibrated ice jam model for open water, thermal, ice jam, and ice run conditions. The model was used to compute flood levels for the range of ice conditions in an attempt to validate the various ice

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enhanced model conditions with this available information. The actual elevation of the gauge data was not available for this study so the published data (digitized from **Figure 24**) was shifted to fit within the range of levels computed by the ice enhanced model, depicted in **Figure** 25.

The computed flood levels were based on daily discharge estimates at Fifth Meridian computed by the open water routing model used for the hydrology assessment (**Appendix A**). A photograph taken during the ice run (refer to photo 4 in **Appendix E**) indicates flood levels neared the low chord of the unnamed bridge in Garden River. The low chord elevation at the bridge is depicted on **Figure 25** for comparison. The results of this validation attempt are inconclusive, yet the appear to be within a plausible range of values indicated by the measurements reported by Jasek (2019).

5.2.3 Ice Jam Frequency Analysis

The parameter of interest for ice jam flood frequency analysis is flood level. This differs from open water where the parameter of interest is discharge. For an ice jam flood condition, there are a range of flood levels that could be associated with a single discharge because the flood level magnitude resulting from an ice jam depends on factors other than discharge – for example: ice thickness, ice jam extent (with head and toe locations), toe thickness, and under ice roughness. The more meaningful parameter for ice jam flood frequency is ice jam flood level. While the approach used to determine ice jam flood level frequency is slightly different than for the open flood frequency, the resulting flood frequency magnitudes are considered technically equivalent.

Ice jam flood frequencies were determined for the 1:20 to 1:500 ice jam floods. A variety of ice affected flood conditions may be experienced over this range of flood magnitudes, including accumulations of loose ice, ice runs, hydraulically thickened ice jams, partially developed ice jams, and fully developed ice jams. For this investigation three ice conditions, described in the previous section (thermal, ice jam, and ice run), were used to account for the range of ice affected flood conditions experienced at the study site. Conditions for ice affected flooding vary, however, it was considered clear and most convenient to denote the ice affected flood frequencies as *ice jam* flood frequencies. Further, most major ice affected flooding is attributed to ice jam floods. The ice jam frequency analysis included the following tasks, as described below.

- Ice Jam Data Preparation
- Monte Carlo Analysis
- Ice Jam Flood Frequency Estimates.

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5.2.3.1 Ice Jam Data Preparation

Breakup discharge and water level data at both 07HF001 Peace River at Fort Vermilion and 07KC001 Peace River at Peace Point were inspected on a year-by-year basis to determine the maximum breakup level, breakup discharge, and breakup type (thermal, ice run, or ice jam). Breakup type was classified by inspection of the available continuous water level hydrographs (plots of digital time series data or scanned images of pen recorder charts). The approach was based on the following:

- Years in which the breakup hydrograph showed a relatively gradual and small incremental rise in water level were interpreted as thermal breakup.
- Years in which the breakup hydrograph showed a rapid rise in water level followed by a rapid or gradual fall were interpreted as an ice run.
- Years in which the breakup hydrograph showed a rapid rise in water level with a sustained peak water level were interpreted as an ice jam.

Table 5-3 summarizes the breakup levels, discharge, and type, determined for the Fort Vermilion and Peace Point gauges. The analysis was supported by information documented by others in prior studies or observational reporting. Those years where breakup type was based on evidence that was previously documented are indicated in the table. Supporting details pertaining to these stations are as follows.

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07HF001 Peace River at Fort Vermilion

NHC (2022) determined the spring breakup water levels and discharges at the 07HF001 Peace River at Fort Vermilion gauge for the periods of 1963 to 1967, 1997, and 2005 to 2019. In addition, NHC (2022) determined the breakup mechanisms for the 1980, 1982 to 1985, 1990, and 2005 to 2019 spring breakups. The NHC (2022) breakup data series was extended for the 2020, 2022, and 2023 breakup periods by inspecting the continuous water level data series and applying the above methodology to determine breakup mechanisms. NHC (2022) classified breakup mechanism based on observational data. This resulted in the breakup mechanism remaining unclassified for the periods of 1986 to 1989 and 1991 to 1993 despite there being sufficient water level data. Therefore, the breakup mechanisms for these periods were able to be determined by applying the above methodology to the available water level hydrographs. Breakup mechanisms were further refined for the period of 2018 - 2023 from the mechanisms referenced in the EPA Breakup reports for 2018, 2019, 2020, 2022, 2023[4]. The results of the analysis are presented in **Table 5-3**.

[4] Peace River Ice Observations Operational Reports. Provided by River Forecast Center River Engineering and Technical Services. Alberta Environment and Parks (2017 through 2023).

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07KC001 Peace River at Peace Point

Breakup mechanisms were determined at the 07KC001 Peace River at Peace Point gauge by applying the above methodology to the continuous water level data (1996 to 2023) and a combination of strip chart and CRID data (1960 to 1995). Breakup mechanisms were further refined from the 1997 Peace Athabasca Delta Flood Report (Giroux 1997) and the 2018, 2020, 2022, and 2023 EPA Spring Breakup Reports (EPA 2018, 2020, 2022, 2023). The results of the analysis are presented in **Table 5-3**.

5.2.3.2 Overview and Approach

There are essentially two methods for determining flood level frequency: direct methods which derive flood level frequency directly from a population of observed ice-affected flood levels; and indirect methods which determine flood level frequency from a population of synthesized ice-affected flood levels.

The **direct method** follows a simple approach where the historical record is reviewed on a yearly basis to identify peak ice-affected flood levels, and then, undertake a frequency analysis by methods like that used for the open water analysis. Unfortunately, this method was not an option as observational data (at the study area) required to apply this simple method (i.e. hydrometric record) are not available.

An alternative approach, an **indirect method**, was used to estimate ice jam flood level frequencies for this study. There are a few different indirect methods available for frequency analysis. The reader is referred to a recent publication by Beltaos (2021) which provides an overview of direct and indirect methods for ice jam frequency estimation. Case study examples comparing direct and indirect methods are also provided by Healy and Kovachis (2023). The adopted method is akin to the so-called G-C method described by Beltaos (2021) which was originally introduced by Gerard and Calkins (1984). The method is a type of stochastic analysis and in this study, it is referred to as a Monte Carlo analysis.

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Table 5-3 Peak Spring Breakup Summary for 07HF001 and 07KC001 gauges

Year	07HF001- Peace River at Fort Vermilion				07KC001- Peace River at Peace Point			
	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type
1922	1922-05-06 0:00	N/A	3680	N/A	No Data Available			
No Data Available from 1923-1933								
1934	1934-04-22 0:00	15.07	N/A	N/A	No Data Available			
No Data Available from 1935-1949								
1950	1950-05-07 0:00	8.97	N/A	N/A	No Data Available			
No Data Available from 1951-1959								
1960	No Data Available from 1960-1962				1960-04-29 13:45	7.39	1880	Thermal
1961					No Data Available		3030	Thermal
1962					1962-05-04 19:00	10.14	3350	Ice Run
1963	1963-05-23 0:00	12.07	5584	N/A	1963-05-14 0:00	13.20	5150	Ice Run
1964	1964-05-12 0:00	5.33	1900	N/A	1964-05-06 2:30	7.74	3000	Thermal
1965	1965-04-29 0:00	10.04	3960	N/A	1965-05-02 18:20	11.67	4400	Ice Jam
1966	1966-05-04 0:00	6.54	1730	N/A	1966-05-08 20:30	10.18	4700	Ice Run
1967	1967-05-03 0:00	5.47	N/A	N/A	1967-05-09 18:00	11.87	5320	Ice Run
1968	No Data Available from 1968-1973				No Data Available		1270	N/A
1969					1969-04-22 13:30	9.84	3000	Ice Jam
1970					No Data Available			
1971					1971-04-27 13:55	8.3	1700	Thermal
1972					No Data Available			
1973					1973-04-28 10:45	10.16	4640	Ice Run

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Year	07HF001- Peace River at Fort Vermilion				07KC001- Peace River at Peace Point			
	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type
1974	1974-05-01 0:00	7.588	6510	N/A	1974-04-30 6:00	13.05	6500	Ice Run
1975	1975-05-07 0:00	4.52	2340	Thermal	No Data Available			
1976	1976-05-09 0:00	5.56	3540	N/A	1976-04-20 0:00	10.21	3820	Ice Run
1977	1977-05-16 0:00	6.86	5320	N/A	1977-04-22 13:10	9.08	3540	Thermal
1978	1978-05-17 0:00	6.55	1820	N/A	1978-05-02 16:50	9.23	2780	Ice Jam
1979	1979-05-11 0:00	8.45	2778	N/A	1979-05-11 18:20	11.86	5380	Ice Run
1980	1980-05-07 0:00	3.364	1355	Thermal	1980-04-25 19:05	6.23	2100	Thermal
1981	1981-05-02 0:00	5.998	2921	N/A	1981-05-02 3:00	10.97	4150	Ice Jam
1982	1982-05-01 0:00	7.199	2184	Thermal	No Data Available			
1983	1983-04-27 0:00	6.86	1845	Thermal	1983-05-02 10:05	9.69	2560	Ice Jam
1984	1984-04-17 0:00	6.911	1666	Thermal	1984-04-20 16:10	8.63	2640	Ice Run
1985	1985-05-03 0:00	7.77	2672	Thermal	1985-05-07 15:05	9.46	4000	Ice Run
1986	1986-04-28 0:00	7.263	2390	Ice Run	1986-05-05 16:55	8.98	3040	Thermal
1987	1987-04-22 0:00	9.01	2976	Ice Jam	No Data Available			
1988	1988-04-07 0:00	5.907	2194	Thermal	1988-04-29 16:10	9.66	3200	Ice Run
1989	1989-05-02 0:00	6.512	1516	Thermal	1989-05-06 18:29	10.97	3600	Ice Jam
1990	1990-04-23 0:00	7.372	1656	Ice Run	1990-04-24 21:30	7.76	2950	Ice Run
1991	1991-04-28 0:00	7.178	2883	Ice Run	1991-04-30 0:00	10.13	4540	Ice Run
1992	1992-04-09 0:00	7.678	3117	Thermal	1992-04-27 1:26	11.56	4800	Ice Run
1993	1993-04-21 0:00	6.722	1992	Ice Run	1993-05-01 1:02	6.90	2480	Thermal
1994	No Data Available from 1994-1996				1994-04-28 8:21	13.52	5310	Ice Jam
1995					1995-05-08 8:31	7.96	3050	Thermal

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Year	07HF001- Peace River at Fort Vermilion				07KC001- Peace River at Peace Point			
	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type
1996					1996-04-25 15:57	13.16	4800	Ice Jam
1997	1997-04-25 0:00	10.698	5303	N/A	1997-04-29 21:55	13.97	9000	Ice Jam
1998	No Data Available from 1998-2004				1998-04-24 7:45	9.02	3810	Ice Run
1999					No Data Available			
2000					2000-04-28 10:30	5.88	1950	Thermal
2001					2001-05-07 7:15	9.72	3120	Ice Jam
2002					2002-05-13 23:15	9.35	3980	Ice Jam
2003					2003-05-02 17:15	14.33	4430	Ice Jam
2004					2004-05-06 0:00	9.73	3880	Ice Run
2005	No Data Available			Thermal	2005-04-23 0:00	N/A	4700	N/A
2006	2006-04-18 14:31	6.067	1980	Thermal	2006-04-26 9:45	6.89	2040	Thermal
2007	2007-04-27 21:16	9.701	4900	Ice Run	2007-04-28 2:25	12.58	6950	Ice Jam
2008	2008-04-20 6:46	6.782	2430	Thermal	2008-05-05 12:59	11.47	4050	Ice Run
2009	2009-04-28 17:01	7.074	2260	Thermal	2009-05-01 13:30	8.36	3090	Thermal
2010	2010-04-19 23:46	6.022	2290	Thermal	2010-04-19 2:10	7.07	2100	Thermal
2011	2011-04-26 17:01	6.094	2120	Thermal	2011-05-01 22:20	9.18	4640	Ice Run
2012	2012-04-26 17:31	6.038	1820	Thermal	2012-04-30 8:25	8.47	2380	Ice Jam
2013	2013-05-01 11:31	8.705	4750	Ice Jam	2013-05-05 17:30	9.84	5130	Ice Run
2014	2014-04-27 0:00	9.968	3480	Ice Jam	2014-05-03 11:50	11.75	6450	Ice Jam
2015	2015-04-15 10:51	7.004	3120	Thermal	2015-04-21 6:50	9.04	3090	Ice Run
2016	2016-04-13 6:51	6.180	2100	Thermal	2016-04-28 13:25	8.02	1970	Thermal
2017	2017-04-27 6:26	7.277	1860	Thermal	2017-05-04 20:50	8.45	3260	Thermal

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Year	07HF001- Peace River at Fort Vermilion				07KC001- Peace River at Peace Point			
	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type	Date-Time	Gauge Level (m)	Discharge (m^3/s)	Breakup Type
2018	2018-04-29 16:55	12.279	5120	Ice Jam	No Data Available			Ice Run
2019	2019-04-09 15:40	5.998	2650	Ice Run	2019-04-19 1:20	7.01	2450	Thermal
2020	2020-04-28 4:00	14.254	8800	Ice Jam	2020-05-04 14:45	13.41	8240	Ice Jam
2021	No Data Available			Thermal	2021-05-07 10:25	9.65	3640	Ice Run
2022	2022-04-29 16:15	7.490	3420	Thermal	2022-05-05 20:25	11.46	5320	Ice Run
2023	2023-04-25 4:40	6.032	2300	Thermal	2023-04-27 5:30	7.37	2070	Thermal

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5.2.3.3 Monte Carlo Analysis

Based on our review of available studies, reports, and annual flood level information for the nearest gauges, it was determined that highest ice-affected flood levels were associated with breakup. As such the analysis was based on peak breakup flood levels.

The Monte Carlo analysis applied to this study was an indirect method that synthesized a distribution of breakup flood level data that captured the full range of breakup flood level magnitudes. It relied on pre-calculated relationships between flood level and breakup discharge (rating curves) for a range of breakup ice conditions. These rating curves were calculated by the ice enhanced model. The resulting family of rating curves provided representative flood levels at the study location for the full range of anticipated breakup flood level scenarios.

In the absence of data in the study area, the analysis relied on data collected by WSC at the nearest upstream and downstream gauges, Peace River at Fort Vermilion and Peace River at Peace Point, respectively. The data were examined for peak breakup discharge, characterization of breakup, and assessing the credibility of the estimated breakup flood frequency distributions.

The first stage of the Monte Carlo analysis (steps 1 through 4) was to calculate the breakup discharge distributions, characterize breakup by type, and determine the relationship between breakup discharge and breakup flood level according to breakup type, as follows.

1. Determine the peak breakup level, corresponding discharge, and dominant breakup type by year. Three different breakup types were identified and classified as thermal, mechanical resulting in a fully developed ice jam, and mechanical resulting in an ice run or partially developed ice jam (denoted as thermal, ice jam, or ice run). The results of the year-by-year analysis are listed in **Table 5-3**.
2. Determine the breakup discharge frequency relationship. The breakup discharge flood frequency distributions are defined by the peak breakup discharge values found in Step 1.
3. Estimate the ratios of breakup types from the statistics obtained from the observed breakup classification determined in Step 1. These provide the probability of occurrence factors for the various breakup types (thermal, ice, jam, or ice run) used by the Monte Carlo analysis. Probability factors obtained from these statistics are listed in **Table 5-4**.
4. Develop a family of ice-affected flood level profiles for each breakup type (thermal, ice jam, and ice run). This was achieved by computing water level profiles over a range of ice conditions and breakup discharges, resulting in a family of rating curves at each model cross section according to breakup type.

The second stage of the Monte Carlo method (steps 5 through 9) proceeded according to the following steps, which were repeated 1 million times, to form a very large sample of breakup flood levels for direct approximation of the ice jam flood level frequency distribution.

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5. Randomly select a value from the breakup discharge frequency distribution (recall Step 2).
6. Randomly select a breakup type based on the probability factors for the various breakup types (recall Step 3).
7. Determine the breakup flood level associated with the randomly selected breakup discharge value and randomly selected breakup type according to the breakup rating curves pre-calculated in Step 4.
8. Store the breakup flood level to a synthesized sample of breakup levels and repeat many times (1,000,000 iterations).
9. Rank and plot the series with a standard plotting position formula to form a distribution of breakup flood levels and compare to the estimated breakup flood levels based on observational data.

A simple script (Python) was used to conduct the analysis which easily accommodate arrays with a dimension of 1,000,000 that would otherwise be impractical for most spreadsheet applications (at least for those available at the time of this study). By choosing a very large sample size the analysis provides frequency estimates at very large recurrence intervals (i.e. 1:1000) that are repeatable.

Table 5-4 Summary Statistics of Breakup Types for Monte Carlo Probability Factors

Breakup Type		Number of Historic Events	Fraction of Total
Fort Vermilion			
Thermal		22	0.67
Mechanical	Ice Run	6	0.18
	Ice Jam	5	0.15
Peace Point			
Thermal		13	0.22
Mechanical	Ice Run	29	0.50
	Ice Jam	16	0.28

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5.2.3.4 Ice Jam Flood Frequency Estimates

Breakup distributions were determined for a range of test scenarios that considered different combinations of breakup discharge distributions and breakup ice types (probability factors). Scenarios were examined for breakup discharge frequency distributions of type Pearson 3 (Q_{P3}), Log-Pearson 3 (Q_{LP3}), kernel density estimation (Q_{KDE}), and log kernel density estimation ($Q_{LOG\ KDE}$) with ice type probability factors for thermal breakup, mechanical breakup as an ice run, and mechanical breakup as a fully developed ice jam [$P_{Thermal}$, $P_{Ice\ Run}$, $P_{Ice\ Jam}$,]. Probability factors were based on statistics of the break up types identified in the year-by-year analysis

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(summarized in **Table 5-4**). Flood frequency estimates for tested for nine scenarios were tested as listed in **Table 5-5.** The results of each test are included in **Appendix F**.

Table 5-5 Ice Jam Flood Frequency Estimation Scenarios

Scenario	Breakup Discharge Distribution (P3, LP3, or KDE)	Ratios by Breakup Type [$P_{Thermal}$, $P_{Ice\ Run}$, $P_{Ice\ Jam}$,]
1 – FV Q_{P3} | $FV_{ice\ types}$	Fort Vermilion, P3	Fort Vermilion, [0.67, 0.18, 0.15]
2 – FV Q_{LP3} | $FV_{ice\ types}$	Fort Vermilion, LP3	Fort Vermilion, [0.67, 0.18, 0.15]
3 – FV Q_{KDE} | $FV_{ice\ types}$	Fort Vermilion, KDE	Fort Vermilion, [0.67, 0.18, 0.15]
4 – FV $Q_{LOG\ KDE}$ | $FV_{ice\ types}$	Fort Vermilion, KDE	Fort Vermilion, [0.67, 0.18, 0.15]
5 – PP Q_{P3} | $PP_{ice\ types}$	Peace Point, P3	Peace Point, [0.22, 0.50, 0.28]
6 – PP Q_{LP3} | $PP_{ice\ types}$	Peace Point, LP3	Peace Point, [0.22, 0.50, 0.28]
7 – PP Q_{KDE} | $PP_{ice\ types}$	Peace Point, KDE	Peace Point, [0.22, 0.50, 0.28]
8 – PP $Q_{LOG\ KDE}$ | $PP_{ice\ types}$	Peace Point, KDE	Peace Point, [0.22, 0.50, 0.28]
9 – FV Q_{P3} | $PP_{ice\ types}$	Fort Vermilion, P3	Peace Point, [0.22, 0.50, 0.28]
10 – FV Q_{LP3} | $PP_{ice\ types}$	Fort Vermilion, LP3	Peace Point, [0.22, 0.50, 0.28]
11 – FV Q_{KDE} | $PP_{ice\ types}$	Fort Vermilion, KDE	Peace Point, [0.22, 0.50, 0.28]
12 – FV $Q_{LOG\ KDE}$ | $PP_{ice\ types}$	Fort Vermilion, KDE	Peace Point, [0.22, 0.50, 0.28]

Scenario 12 – FV $Q_{LOG\ KDE}$ \| $PP_{ice\ types}$ was selected for the design ice jam flood frequencies (refer to **Figure 26**). This scenario was considered to be the most credible of the nine scenarios tested for the following reasons.

- Breakup discharge at Fort Vermilion is more indicative of the breakup discharge in the study area. This also agrees with the findings of the open water hydrology where flows at Fifth Meridian, located a few kilometers upstream of the study area, were only slightly lower than those at Fort Vermilion. Further, the Peace River widens significantly within and downstream of the study area. This widening would provide attenuation of flow peaks downstream to Peace Point.

- The breakup types at Fort Vermilion (mostly thermal) are not very indicative of breakup at Garden River. A review of the breakup reports from EPA and other breakup accounts indicates that breakups at Garden River are mostly dynamic. And so, the types of breakup characteristic to Peace Point were considered to be more indicative of breakup at Garden River.

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- The breakup discharge distribution determined by log kernel density estimation (LOG KDE) provided a better fit to the observed breakup distribution than typical theoretical distributions (e.g. LP and LP3). The KDE distribution provided unrealistic underestimations of flows for low return periods.

The results of the Monte Carlo Analysis were then used to develop the ice jam flood level frequency profiles as describe in the next section.

5.2.4 Ice Jam Flood Frequency Profiles

It was not technically feasible to map inundation with the 1D enhanced ice model geometry. The 1D cross sections are not able to sufficiently extend the flood elevations from the 1D Peace River main channel into the flood floodplain in a plausible manner, certainly not as realistic as was achieved with 2D overbank areas mapped for the open water model results. The adopted approach was to use the open water model to calculate flood level profiles that fit with the ice jam design flood levels calculated by the Monte Carlo Analysis. This approach explicitly accounts for the flood extents throughout the entire floodplain in a manner similar to the open water mapping. By this approach, a more credible flood surface is achieved in the floodplain than would be feasibly achieved with 1D cross section information.

The resulting ice jam flood frequency profiles are depicted on **Figure 27**. The Monte Carlo flood level frequency estimates are included for comparison. An ice jam flood frequency analysis was not conducted for Garden Creek.

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6 OPEN WATER & ICE JAM FLOOD INUNDATION MAPS

Flood inundation mapping provides a visual display of the extent of inundation for a given design flood scenario. A separate flood inundation map was created for each of the 13 open water flood and 8 ice jam flood frequency estimates. These maps correspond to return periods ranging from 1:2 to 1:1000 for open water floods and 1:20 to 1:500 for ice jam floods. The open water inundation maps cover both the Peace River and Garden Creek while the ice jam inundation maps cover the Peace River including its backwater extents along Garden Creek. **Appendix H** and **Appendix I** provide flood inundation maps for all open water and ice jam flooding scenarios, respectively. The following describes the process followed to produce the flood inundation maps.

6.1 Methodology

The methodology used to create the flood inundation maps followed these steps, details of which are provides in the subsequent section. Since the open water model was used to simulate ice jam design flood profiles, the approach below is applicable to both flood mechanisms (open water and ice jam).

1. Create a water surface elevation (WSE) triangular irregular network (TIN) that is representative of a contiguous flood surface throughout the modelled reaches and floodplain.
2. Create a WSE grid with elevation values based on the WSE TIN.
3. Create a depth grid based on the difference between the WSE grid and underlying DTM.
4. Create inundation polygons based on the depth grid such that the polygon extents delineate positive depth areas, with polygon edges following zero depth contours.
5. Adjust the inundation polygons manually for areas where depths and hydraulic connectivity cannot be adequately resolved by the preceding steps.
6. Finalize inundation extents to include manual edits and smoothing.

6.1.1 Water Surface Elevation TIN

The TIN inputs were based on model geometry and calculated water levels. Additional geometry was included to define the limits of the coupled 1D/2D model domain. The following describes the geometry required from the 1D and 2D model domains.

The TIN inputs for the 1D modelled areas were based on the constant WSE at each cross section. Cross section interpolation nodes consisting of point WSE values were used to inform interpolation between cross sections. The nodes were placed along linear interpolation paths

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which included river centerlines and riverbank lines. The extent of the TIN domain was clipped to the cross section edge lines corresponding to the edge of the 1D model domain.

The TIN inputs for the 2D modelled area were based on calculated water levels for all the 2D computation cell centres (point water surface elevation values centered at each 2D computation cell). Interpolation of the TIN surface was informed by the breaklines used in the model. The extent of the TIN domain was clipped to the extent of the model 2D flow area.

6.1.2 Water Surface Elevation and Depth Grids

The WSE grid was created directly from the WSE TIN using ArcGIS Pro tools. The WSE grid provides a raster data set with water surface elevation values at the same cell resolution and is congruent with the underlying DTM. The depth grid was created by subtracting the underlying DTM elevation values from the WSE grid values.

6.1.3 Inundation Polygons

Inundation polygons were created through a series of steps, described as follows.

Filtered Depth Mask: The first step was to create an inundation mask of wetted areas found within the depth grids. This step is based solely on positive depth values with no filtering. Negative depth values indicate dry cells and are assigned a NoData value. Positive depth values denote wet cells and were assigned a value of 1. This mask was denoted as the positive depth mask. The positive depth mask was further processed and filtered to aggregate contiguous areas of wet cells and remove patchy dry areas. This also minimizes the creation of small self-intersecting loops and knots in the resulting inundation polygon. This final mask was denoted as the filtered depth mask.

Initial Inundation Polygons: Initial inundation polygons are created through a series of steps, beginning with conversion of the filtered depth mask into polygons. These initial inundation polygons were further processed by ensuring there are no multipart polygons and dissolving contiguous polygon features; removing small, isolated polygon areas (less than 100 m^2); and, filling small holes inside polygons (less than 100 m^2).

Inundation Areas Classification: The initial inundation polygons (updated with manual edits) were then examined and visually classified as direct inundation areas (including areas that were identified to be connected by culverts), areas behind roads, and isolated areas within lagoons. The final polygon areas (classified as direct inundation areas) were then used to mask the WSE and depth gridded datasets.

Final Inundation Extents: The final polygon areas were then smoothed to create the final inundation extents. The Polynomial Approximation with Exponential Kernel method and a smoothing tolerance of 3 m was applied. Further visual checks were conducted to ensure proper

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nesting of flood extent limits across the range of flood frequency estimates. In some instances, the smoothing process resulted in very small overlaps (fractions of a metre) between flood frequencies, particularly where the edges of inundation followed steep banks. In these instances, the lower flood frequency extents were constrained by higher frequency events.

6.2 Flood Inundation Areas

The extent of flood inundation is evident in the flood inundation maps (**Appendix H** and **Appendix I**). The following provides context for areas exposed to direct flooding. **Table 6-1** and **Table 6-2** provide a streamwise summary of developed areas and infrastructure impacted by flooding over the range of open water flood frequencies for the Peace River and Garden Creek, respectively. **Table 6-3** and **Table 6-4** provide the same summaries for ice jam flood frequencies along Peace River and Garden Creek, respectively. Cells highlighted in blue denote specific frequency events for which impacts are anticipated for each corresponding location. Impacts may not occur at all locations or for all frequency events. Frequency events are shown within cells for ease of reference and are abbreviated for table formatting purposes (e.g., "100" corresponds to the 1:100 flood shown in the column header).

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Table 6-1 Impacted Areas Across a Range of Open Water Flood Frequencies along the Peace River

Impacted Areas along Left Floodplain													River KM	Impacted Areas along Right Floodplain											
1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000		1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
													0 to 29.0	Peace River side channel mouth (1.2 km)											
														2	5	10	20	35	50	75	100	200	350	500	750	1000
Boat launch access road at old cutoff (29.0 km – 30.3 km)														Peace River side channel out (32.0 km)											
2	5	10	20	35	50	75	100	200	350	500	750	1000		2	5	10	20	35	50	75	100	200	350	500	750	1000
Garden River airstrip (30.3 km to 31.7 km)																										
Sister Gloria School (30.7 km)																										
													29.0 to 33.0													
Medical centre (30.8 km)																										
Garden Creek at the mouth (30.8 km)																										
2	5	10	20	35	50	75	100	200	350	500	750	1000														
South community (31.2 km – 32.4 km)																										
								200	350	500	750	1000														
													33.0 to 47.4													

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Table 6-2 Impacted Areas Across a Range of Open Water Flood Frequences along Garden Creek

Impacted Areas along Left Floodplain													River KM	Impacted Areas along Right Floodplain											
1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000		1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
North community (0.300 km to 1.4 km)													0 to 1.6	South community by bridge (0.600 km to 1.2 km)											
								200	350	500	750	1000													750	1000
Sewage pump station (0.9 km to 1.0 km)																										
				35	50	75	100	200	350	500	750	1000														
Unnamed Road Bridge													1.0	Unnamed Road Bridge											
			20	35	50	75	100	200	350	500	750	1000					20	35	50	75	100	200	350	500	750	1000
													1.6 to 11.0													
Hwy 58 Bridge													10.5	Hwy 58 Bridge											
						75	100	200	350	500	750	1000								75	100	200	350	500	750	1000
Rural residences (14.3 km to 14.5 km)													11.0 to 20.2													
Sewage lagoon (17.0 km to 18.0 km)																										
Seasonal residence (19.0 km to 19.1 km)																										

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Table 6-3 Impacted Areas Across a Range of Ice Jam Flood Frequencies along the Peace River

Impacted Areas along Left Floodplain								River KM	Impacted Areas along Right Floodplain							
1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500		1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500
								0 to 29.0	Peace River side channel mouth (1.2 km)							
									20	35	50	75	100	200	350	500
Boat launch access road at old cutoff (29.0 km – 30.3 km)								29.0 to 33.0	Peace River side channel out (32.0 km)							
20	35	50	75	100	200	350	500		20	35	50	75	100	200	350	500
Garden River airstrip (30.3 km to 31.7 km)																
Sister Gloria School (30.7 km)																
Medical centre (30.8 km)																
Garden Creek at the mouth (30.8 km)																
20	35	50	75	100	200	350	500									
South community (31.2 km – 32.4 km)																
				100	200	350	500									
								33.0 to 47.4								

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Classification: Public

Table 6-4 Impacted Areas Across a Range of Ice Jam Flood Frequencies along Garden Creek

Impacted Areas along Left Floodplain								River KM	Impacted Areas along Right Floodplain							
1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500		1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500
North community (0.300 km to 1.4 km)								0 to 1.6	South community by bridge (0.600 km to 1.2 km)							
					200	350	500								350	500
Sewage pump station (0.9 km to 1.0 km)																
	35	50	75	100	200	350	500									
Unnamed Road Bridge								1.0	Unnamed Road Bridge							
20	35	50	75	100	200	350	500		20	35	50	75	100	200	350	500
								1.6 to 11.0								
Hwy 58 Bridge								10.5	Hwy 58 Bridge							
					200	350	500							200	350	500
Rural residences (14.3 km to 14.5 km)								11.0 to 20.2								
Sewage lagoon (17.0 km to 18.0 km)																
Seasonal residence (19.0 km to 19.1 km)																

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Classification: Public

7 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) is provided in the following sections.

7.1 Floodway & Flood Fringe Terminology

The following provide definitions to relevant terms used in this section as defined in the FHIP guidelines (AEP 2022).

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 1:100 design flood and divides that flood hazard area into floodway and flood fringe zones. It also includes flood fringe sub-zones: 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 1:200 and 1:500 floods.

Floodway

When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard for the 1:100 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 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 more significant in flood maps that are being updated, but t hey may also be included in new flood maps.

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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 illustrate residual flood risk and do not differentiate between areas with deeper and faster moving water and shallower or slower moving water. Protected flood fringe areas were found behind the sewage lagoons located in the floodplain.

7.2 Floodway Determination Criteria

For ice jam flood hazard mapping, there is no velocity criterion for floodway limit determination. Aside from this exception, the floodway limit determination criteria is much the same for open water and ice jam flooding.

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

- Areas in which the depth of water exceeds 1 m, or the flow velocities are greater than 1 m/s (for open water flooding) shall be part of the floodway.
- Exceptions may be made for small backwater areas, ineffective flow areas, and to support creation of 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, which is larger.

Areas of deeper or faster moving water outside of the floodway are identified as high hazard flood fringe. In such reaches, there may be a departure from the aforementioned criteria to provide a hydraulically-smooth path.

7.3 Open Water Flood Hazard Identification

The design flood for open water flood hazard identification in Alberta is typically associated with a natural (non-regulated) peak instantaneous discharge that has a one percent chance of being equaled or exceeded in any given year – an annual exceedance probability, AEP = 1%. This is a flood with a statistical 100-year return period, also commonly referred to as the "1:100 open water flood".

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The following describes the criteria used to determine the floodway and the resulting flood levels and criteria maps used to inform mapping.

7.3.1 Open Water Design Flood Levels & Profile

The open water design flood levels for Peace River and Garden Creek are listed in **Table 7-1** and **Table 7-2**, respectively. The values are reported at river stations corresponding to modelled cross sections for the Peace River and at even river station spaced 300 m apart for Garden Creek. The corresponding flood profiles are the same as the 1:100 open water floods plotted in **Figure** 11 and **Figure 12** for Peace River and Garden Creek, respectively.

Table 7-1 Open water design flood levels – Peace River

River KM	Design Flood Level (m)	River KM	Design Flood Level (m)	River KM	Design Flood Level (m)
47.4	236.05	31.7	235.21	14.8	234.85
44.7	235.85	30.3	235.19	13.2	234.84
43.3	235.78	29.1	235.16	12.2	234.81
42.2	235.69	27.8	235.11	11.0	234.75
41.0	235.63	26.8	235.08	9.7	234.72
39.5	235.61	25.7	235.06	8.4	234.65
38.2	235.51	24.4	234.99	7.1	234.64
37.1	235.45	22.8	234.92	5.9	234.63
35.6	235.41	21.3	234.90	4.1	234.54
34.3	235.36	19.6	234.84	2.2	234.42
33.3	235.33	18.1	234.78	0.0	234.35
32.4	235.27	16.6	234.84		

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Classification: Public

Table 7-2 Open water design flood levels – Garden Creek

River KM	Design Flood Level (m)	River KM	Design Flood Level (m)	River KM	Design Flood Level (m)
20.2	239.52	13.5	236.13	6.6	235.48
20.1	239.50	13.2	236.05	6.3	235.48
19.8	239.30	12.9	236.03	6.0	235.45
19.5	239.14	12.6	236.02	5.7	235.43
19.2	239.01	12.3	235.99	5.4	235.40
18.9	238.80	12.0	235.98	5.1	235.38
18.6	238.58	11.7	235.97	4.8	235.35
18.3	238.38	11.4	235.96	4.5	235.35
18.0	238.19	11.1	235.94	4.2	235.34
17.7	238.12	10.8	235.91	3.9	235.33
17.4	238.01	10.5	235.84	3.6	235.32
17.1	237.85	10.2	235.71	3.3	235.30
16.8	237.75	9.9	235.67	3.0	235.29
16.5	237.65	9.6	235.64	2.7	235.28
16.2	237.45	9.3	235.63	2.4	235.26
15.9	237.29	9.0	235.61	2.1	235.25
15.6	237.15	8.7	235.59	1.8	235.25
15.3	236.98	8.4	235.57	1.5	235.24
15.0	236.74	8.1	235.55	1.2	235.23
14.7	236.55	7.8	235.53	0.9	235.22
14.4	236.39	7.5	235.52	0.6	235.21
14.1	236.28	7.2	235.51	0.3	235.20
13.8	236.20	6.9	235.49	0.0	235.20

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7.3.2 Floodway Criteria Maps

With the exception of a few relatively high velocity areas on Garden Creek (near the highway bridge and a few overbank areas alongside the creek), floodway limits were governed by the 1 m depth criteria. The resulting floodway criteria map for open water is provided as **Appendix J**.

Classification: Public

7.4 Ice Jam Flood Hazard Identification

The design flood for ice jam flood hazard identification in Alberta is typically associated with an ice jam water level that has a one percent chance of being equaled or exceed in any given year – an annual exceedance probability, AEP = 1%. This is a flood with a statistical 100-year return period, also commonly referred to as the "1:100 ice jam flood".

The following describes the design flood levels, profile, and criteria for determining the floodway for the ice jam design flood.

7.4.1 Ice Jam Design Flood Levels & Profile

The ice jam design flood levels for Peace River are listed in **Table 7-3**. Ice jam modelling was not completed along Garden Creek; however, backwater from the Peace River is still expected. Water levels along Garden Creek resulting from backwater from ice jams on Peace River are listed in **Table 7-4**. The values are reported at river stations corresponding to modelled cross sections for the Peace River. The corresponding flood profile is the same as the 1:100 ice jam flood plotted in **Figure 27** for Peace River.

Table 7-3 Ice jam design flood levels – Peace River

River KM	Design Flood Level (m)	River KM	Design Flood Level (m)	River KM	Design Flood Level (m)
47.4	236.20	31.7	235.51	14.8	235.15
44.7	236.04	30.3	235.47	13.2	235.14
43.3	235.97	29.1	235.44	12.2	235.12
42.2	235.90	27.8	235.40	11.0	235.08
41.0	235.85	26.8	235.36	9.7	235.05
39.5	235.83	25.7	235.34	8.4	235.00
38.2	235.75	24.4	235.27	7.1	234.98
37.1	235.70	22.8	235.21	5.9	234.97
35.6	235.67	21.3	235.19	4.1	234.87
34.3	235.63	19.6	235.14	2.2	234.78
33.3	235.61	18.1	235.09	0.0	234.73
32.4	235.56	16.6	235.14		

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Classification: Public

Table 7-4 Ice jam design flood levels – Garden Creek

River KM	Design Flood Level (m)	River KM	Design Flood Level (m)	River KM	Design Flood Level (m)
20.2	-	13.5	235.49	6.6	235.49
20.1	-	13.2	235.49	6.3	235.49
19.8	-	12.9	235.49	6.0	235.49
19.5	-	12.6	235.49	5.7	235.49
19.2	-	12.3	235.49	5.4	235.49
18.9	-	12.0	235.49	5.1	235.49
18.6	235.49	11.7	235.49	4.8	235.49
18.3	235.49	11.4	235.49	4.5	235.49
18.0	235.49	11.1	235.49	4.2	235.49
17.7	235.49	10.8	235.49	3.9	235.49
17.4	235.49	10.5	235.49	3.6	235.49
17.1	235.49	10.2	235.49	3.3	235.49
16.8	235.49	9.9	235.49	3.0	235.49
16.5	235.49	9.6	235.49	2.7	235.49
16.2	235.49	9.3	235.49	2.4	235.49
15.9	235.49	9.0	235.49	2.1	235.49
15.6	235.49	8.7	235.49	1.8	235.49
15.3	235.49	8.4	235.49	1.5	235.49
15.0	235.49	8.1	235.49	1.2	235.49
14.7	235.49	7.8	235.49	0.9	235.49
14.4	235.49	7.5	235.49	0.6	235.49
14.1	235.49	7.2	235.49	0.3	235.49
13.8	235.49	6.9	235.49	0.0	235.48

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7.4.2 Floodway Criteria Maps

For the ice jam design flood, the floodway limits were governed by the 1 m depth criteria everywhere. The resulting floodway criteria map for ice jam flooding is provided as **Appendix K**.

Classification: Public

7.5 Governing Design Flood Hazard Determination

Governing design flood hazard mapping reflects the worst case scenario between the 1:100 open water and ice jam floods. In determining the governing design flood hazard scenario, it is possible that either a single flood scenario will dominate an entire river reach or that a hybrid of the two flood scenarios will govern, where only a single flood scenario will govern along any sub-reach.

7.5.1 Governing Design Flood Mechanism

A comparison of the open water and ice jam design flood levels was completed and is shown in **Table 7-5** and **Table 7-6** for the Peace River and Garden Creek, respectively. The governing flood scenario (open water or ice jam) is highlighted in the tables.

Peace River: Ice jam design flood levels exceed open water design flood levels everywhere along the Peace River. The ice jam flood condition governed over the entirety of the Peace River study area.

Garden Creek: Ice jam flooding is not a dominant flood mechanism for Garden Creek and ice conditions were not assessed for Garden Creek. Any major flooding along the creek was attributed to ice-affected backwater from the Peace River. In the lower portions of Garden Creek backwater from ice jam flooding on the Peace River governs. Open water design flood levels are to within 1 cm of ice jam design flood levels near km 6.3. Ice jam design flood levels are millimeters higher than open water design flood levels above km 6.3, for some 300 m; however, km 6.3 provided a more convenient location to demarcate the transition between governing floods. And so, below km 6.3 ice jam flooding was adopted as the governing condition and upstream of km 6.3 open water flooding was adopted as the governing flood condition.

Table 7-5 Comparison of open water and ice jam design flood levels – Peace River

River KM	Flood Level (m)		River KM	Flood Level (m)		River KM	Flood Level (m)	
	Open Water	Ice Jam		Open Water	Ice Jam		Open Water	Ice Jam
47.4	236.05	236.20	31.7	235.21	235.51	14.8	234.85	235.15
44.7	235.85	236.04	30.3	235.19	235.47	13.2	234.84	235.14
43.3	235.78	235.97	29.1	235.16	235.44	12.2	234.81	235.12
42.2	235.69	235.90	27.8	235.11	235.40	11.0	234.75	235.08
41.0	235.63	235.85	26.8	235.08	235.36	9.7	234.72	235.05
39.5	235.61	235.83	25.7	235.06	235.34	8.4	234.65	235.00
38.2	235.51	235.75	24.4	234.99	235.27	7.1	234.64	234.98

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River KM	Flood Level (m)	
	Open Water	Ice Jam
37.1	235.45	235.70
35.6	235.41	235.67
34.3	235.36	235.63
33.3	235.33	235.61
32.4	235.27	235.56

River KM	Flood Level (m)	
	Open Water	Ice Jam
22.8	234.92	235.21
21.3	234.90	235.19
19.6	234.84	235.14
18.1	234.78	235.09
16.6	234.84	235.14

River KM	Flood Level (m)	
	Open Water	Ice Jam
5.9	234.63	234.97
4.1	234.54	234.87
2.2	234.42	234.78
0.0	234.35	234.73

1. The governing design flood mechanism at each cross section is highlighted in green.

Table 7-6 Comparison of open water and ice jam design flood levels – Garden Creek

River KM	Flood Level (m)	
	Open Water	Ice Jam
20.2	239.52	-
20.1	239.50	-
19.8	239.30	-
19.5	239.14	-
19.2	239.01	-
18.9	238.80	-
18.6	238.58	235.49
18.3	238.38	235.49
18.0	238.19	235.49
17.7	238.12	235.49
17.4	238.01	235.49
17.1	237.85	235.49
16.8	237.75	235.49
16.5	237.65	235.49
16.2	237.45	235.49
15.9	237.29	235.49
15.6	237.15	235.49
15.3	236.98	235.49
15.0	236.74	235.49

River KM	Flood Level (m)	
	Open Water	Ice Jam
13.5	236.13	235.49
13.2	236.05	235.49
12.9	236.03	235.49
12.6	236.02	235.49
12.3	235.99	235.49
12.0	235.98	235.49
11.7	235.97	235.49
11.4	235.96	235.49
11.1	235.94	235.49
10.8	235.91	235.49
10.5	235.84	235.49
10.2	235.71	235.49
9.9	235.67	235.49
9.6	235.64	235.49
9.3	235.63	235.49
9.0	235.61	235.49
8.7	235.59	235.49
8.4	235.57	235.49
8.1	235.55	235.49

River KM	Flood Level (m)	
	Open Water	Ice Jam
6.6	235.48	235.49
6.3	235.48	235.49
6.0	235.45	235.49
5.7	235.43	235.49
5.4	235.40	235.49
5.1	235.38	235.49
4.8	235.35	235.49
4.5	235.35	235.49
4.2	235.34	235.49
3.9	235.33	235.49
3.6	235.32	235.49
3.3	235.30	235.49
3.0	235.29	235.49
2.7	235.28	235.49
2.4	235.26	235.49
2.1	235.25	235.49
1.8	235.25	235.49
1.5	235.24	235.49
1.2	235.23	235.49

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River KM	Flood Level (m)	
	Open Water	Ice Jam
14.7	236.55	235.49
14.4	236.39	235.49
14.1	236.28	235.49
13.8	236.20	235.49

River KM	Flood Level (m)	
	Open Water	Ice Jam
7.8	235.53	235.49
7.5	235.52	235.49
7.2	235.51	235.49
6.9	235.49	235.49

River KM	Flood Level (m)	
	Open Water	Ice Jam
0.9	235.22	235.49
0.6	235.21	235.49
0.3	235.20	235.49
0.0	235.20	235.48

1. The governing design flood mechanism at observed river KM locations are highlighted in green.

7.5.2 Governing Design Flood Levels & Profile

Figure 28 and **Figure 29** provide the governing design flood profiles along the Peace River and Garden Creek, respectively. The governing design flood levels (previously indicated in **Table 7-5** and **Table 7-6**) are summarized in **Table 7-7** and **Table 7-8**.

Table 7-7 Governing design flood levels – Peace River

River Station (m)	Design Flood Level (m)
47.4	236.20
44.7	236.04
43.3	235.97
42.2	235.90
41.0	235.85
39.5	235.83
38.2	235.75
37.1	235.70
35.6	235.67
34.3	235.63
33.3	235.61
32.4	235.56

River Station (m)	Design Flood Level (m)
31.7	235.51
30.3	235.47
29.1	235.44
27.8	235.40
26.8	235.36
25.7	235.34
24.4	235.27
22.8	235.21
21.3	235.19
19.6	235.14
18.1	235.09
16.6	235.14

River Station (m)	Design Flood Level (m)
14.8	235.15
13.2	235.14
12.2	235.12
11.0	235.08
9.7	235.05
8.4	235.00
7.1	234.98
5.9	234.97
4.1	234.87
2.2	234.78
0.0	234.73

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Classification: Public

Table 7-8 Governing design flood levels – Garden Creek

River Station (m)	Design Flood Level (m)	River Station (m)	Design Flood Level (m)	River Station (m)	Design Flood Level (m)
20.2	239.52	13.5	236.13	6.6	235.49
20.1	239.50	13.2	236.05	6.3	235.49
19.8	239.30	12.9	236.03	6.0	235.49
19.5	239.14	12.6	236.02	5.7	235.49
19.2	239.01	12.3	235.99	5.4	235.49
18.9	238.80	12.0	235.98	5.1	235.49
18.6	238.58	11.7	235.97	4.8	235.49
18.3	238.38	11.4	235.96	4.5	235.49
18.0	238.19	11.1	235.94	4.2	235.49
17.7	238.12	10.8	235.91	3.9	235.49
17.4	238.01	10.5	235.84	3.6	235.49
17.1	237.85	10.2	235.71	3.3	235.49
16.8	237.75	9.9	235.67	3.0	235.49
16.5	237.65	9.6	235.64	2.7	235.49
16.2	237.45	9.3	235.63	2.4	235.49
15.9	237.29	9.0	235.61	2.1	235.49
15.6	237.15	8.7	235.59	1.8	235.49
15.3	236.98	8.4	235.57	1.5	235.49
15.0	236.74	8.1	235.55	1.2	235.49
14.7	236.55	7.8	235.53	0.9	235.49
14.4	236.39	7.5	235.52	0.6	235.49
14.1	236.28	7.2	235.51	0.3	235.49
13.8	236.20	6.9	235.49	0.0	235.48

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7.5.3 Governing Design Flood Hazard Maps

The resulting flood hazard map is provided as **Appendix L**.

Classification: Public

7.6 Flood Hazard Inundation Areas

Garden Creek

The flood fringe areas include mostly undeveloped areas, with only very limited encroachment into some residential areas near the Unnamed Road Bridge. The floodway is limited to mostly undeveloped areas, some roadway infrastructure (e.g. Hwy 58 Bridge and Unnamed Road Bridge) and only a few developed areas through the community near the Unnamed Road Bridge. The girders on the Hwy 58 Bridge and the Unnamed Road Bridge are impacted by floodwaters. Although there are no major developments or infrastructure within the floodway, the floodway area is expansive.

Peace River

The floodway extends across the channel and almost the entirety of the floodplain. The flood fringe is very limited. In most areas, there is no practical extent of flood fringe due to the floodway extending to steep valley walls. Along the community (river km 33 to 31) the flood fringe and the floodway include some residential areas that are located along the shoreline. Downstream of the community between river km 31 and 29, the floodway encroaches on several boat launches and overtops the local access road.

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Classification: Public

8 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.

8.1 Comparative Studies

For the open water flood hazard, the current 1:100 open water design flood water levels were compared to those associated with discharges that are 10% and 20% higher than the current 1:100 open water flood estimates. This approach is consistent with guidelines prepared by Engineers and Geoscientists British Columbia (EGBC 2018), which 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.

8.2 Results

Figure 30 and **Figure 31** show the resulting profiles of the Peace River and Garden Creek reaches under the two climate change scenarios. Both scenarios generally produce a consistent rise in water levels along the Peace River and most of Garden Creek. The upper reach of Garden Creek, upstream of Hwy 58 where the floodplain widens, responds less to the increased discharges. **Table 8-1** shows the mean, minimum, and maximum differences in water level from the present day 1:100 open water flood baseline for both the 10% and 20% increased discharge scenarios.

Table 8-1 Water level variation under climate change scenarios

River	Variance from 1:100 open water design flood baseline condition (m)					
	1:100 open water flood (+10% Climate Change)			1:100 open water flood (+20% Climate Change)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Peace River	0.40	0.36	0.44	0.78	0.71	0.86
Garden Creek	0.25	0.04	0.38	0.50	0.08	0.75

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Classification: Public

9 CONCLUSIONS

The objectives of this study were to assess river flood-related hazards along approximately 34 km of the Peace River and 19 km of Garden Creek through Mackenzie County, Improvement District No. 24, and the Little Red River Cree Nation of Garden River. The study was divided into eight major project components: Survey and Base Data Collection, Open Water Hydrology Assessment, Open Water Hydraulic Modelling, Open Water Flood Inundation Mapping, Ice Jam Flood Assessment and Modelling, Ice Jam Flood Inundation Mapping, Design Flood Hazard Identification and Mapping, and Climate Change Impacts. This report summarized the work of all eight components.

Ice jam flooding is the governing design flood condition for the Peace River and lower 6.3 km of Garden Creek (alongside Garden River). The upper portions of Garden Creek (above km 6.3 and the above the highway) are governed by open water flooding. The floodway extends to the steep valley walls along the Peace River leaving little to no practical extent of flood fringe due to the valley confinement.

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Classification: Public

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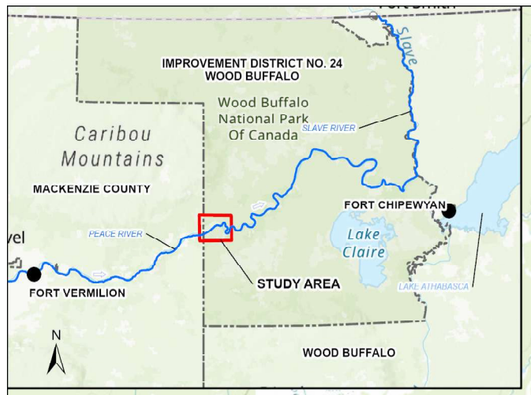
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Classification: Public

FIGURES

DRAFT

Classification: Public



Mackenzie County

Improvement District No. 24
Wood Buffalo

Peace River

Garden Creek

Community of
Garden River

Garden Creek
at the mouth

Peace River

Peace River at
Fifth Meridian
(Discontinued WSC
Station 07KA002)

N

DRAFT

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:120,000

0 2 4 6 KM

Coordinate System: NAD 1983 CSRS 3TM 114;
Units: Metres

Alberta
Canada
nhc

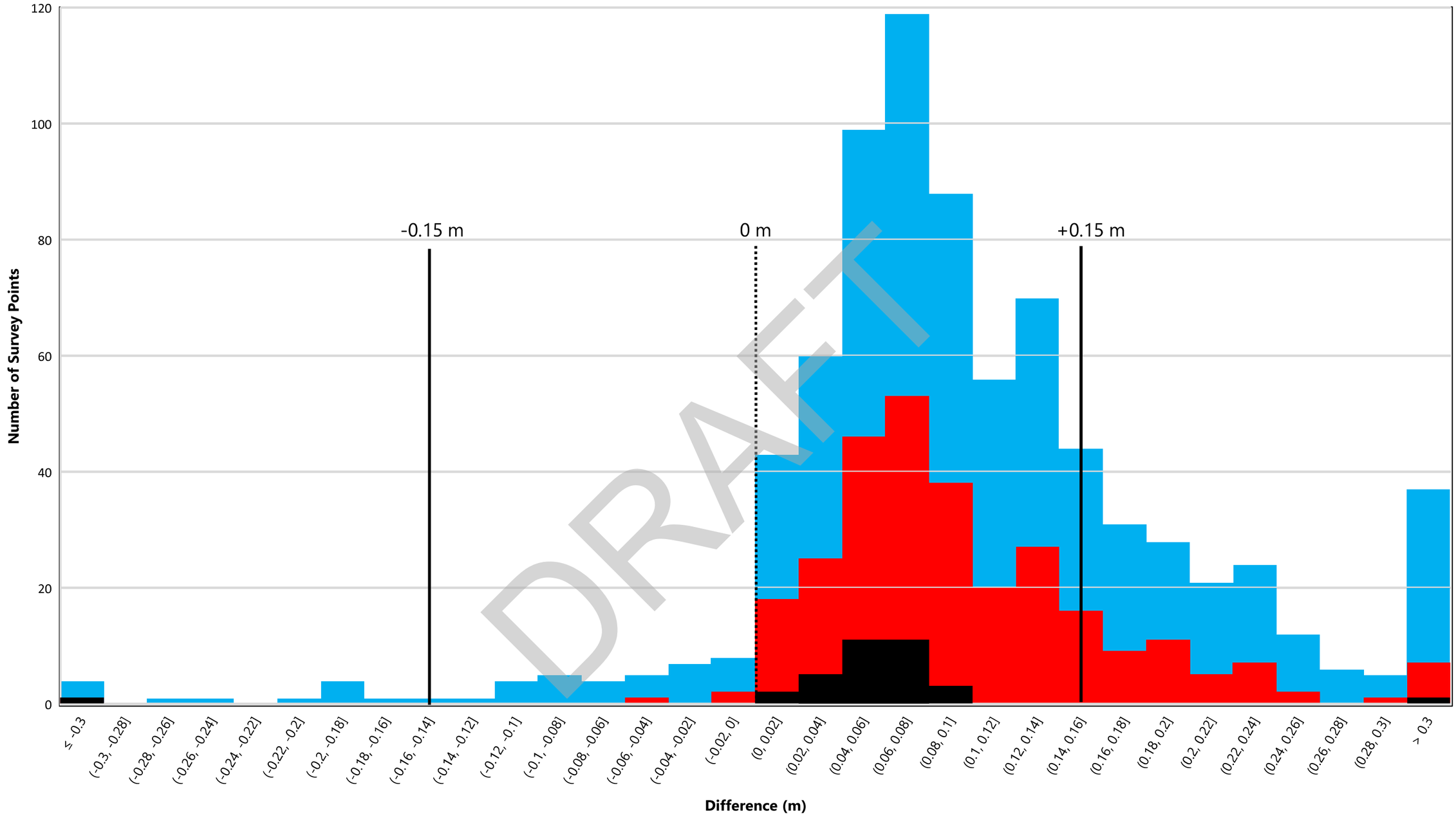
- FLOOD FREQUENCY ESTIMATE LOCATION
- RIVER CENTRELINE
- MAPPING BOUNDARIES
- MUNICIPAL BOUNDARIES
- FLOW DIRECTION

GARDEN RIVER FLOOD STUDY

STUDY AREA

Job: 1009251	Date: May-2026	FIGURE 1

Classification: Public



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Notes:
1. Difference is taken as DTM Elevation – Surveyed Elevation

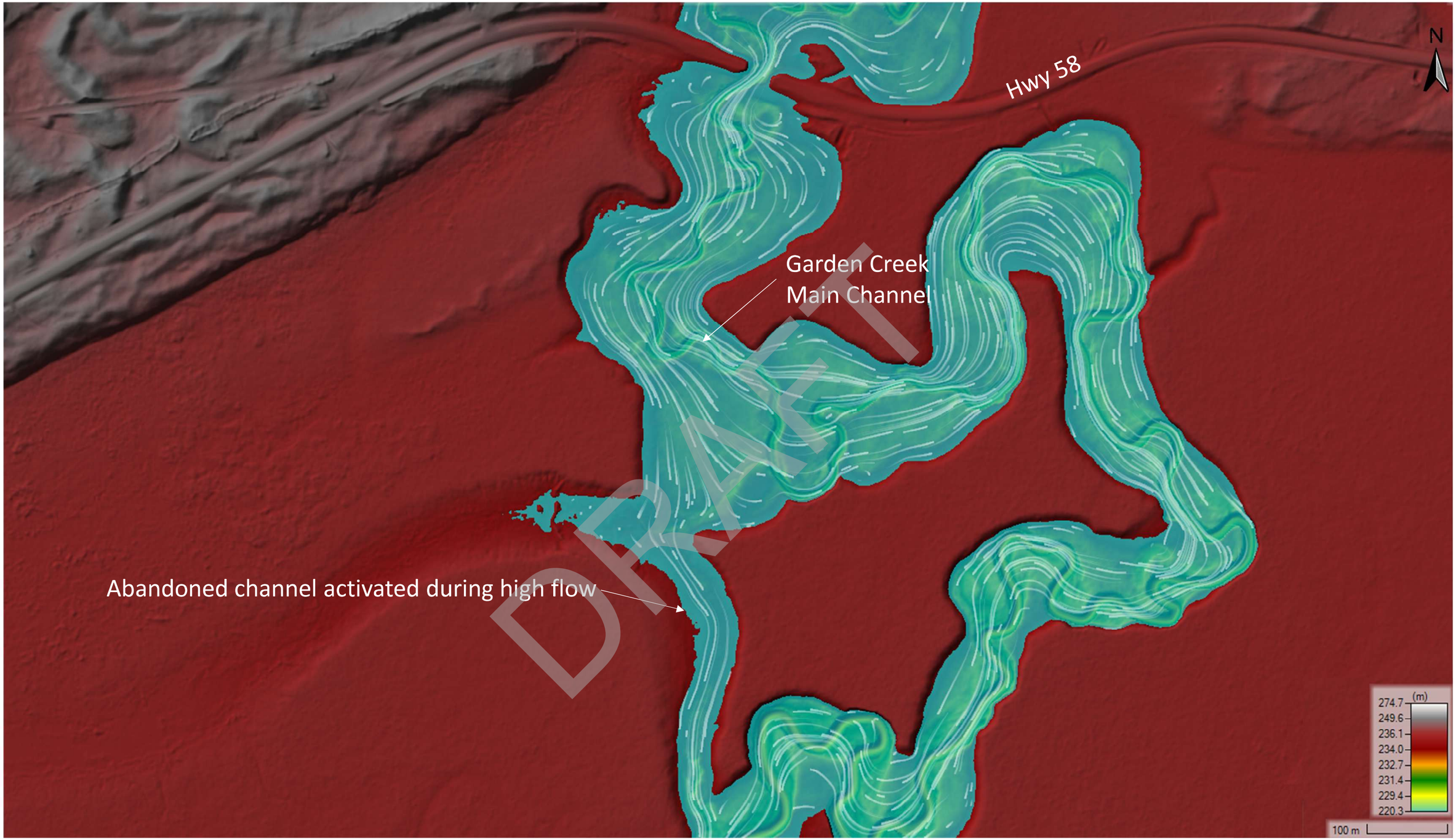
- bank, ground, and hard surface
- ground, and hard surface
- hard surface

GARDEN RIVER FLOOD STUDY

COMPARISON BETWEEN DTM AND SURVEY DATA

Job: 1009251	Date: May-2026	FIGURE 2

Classification: Public



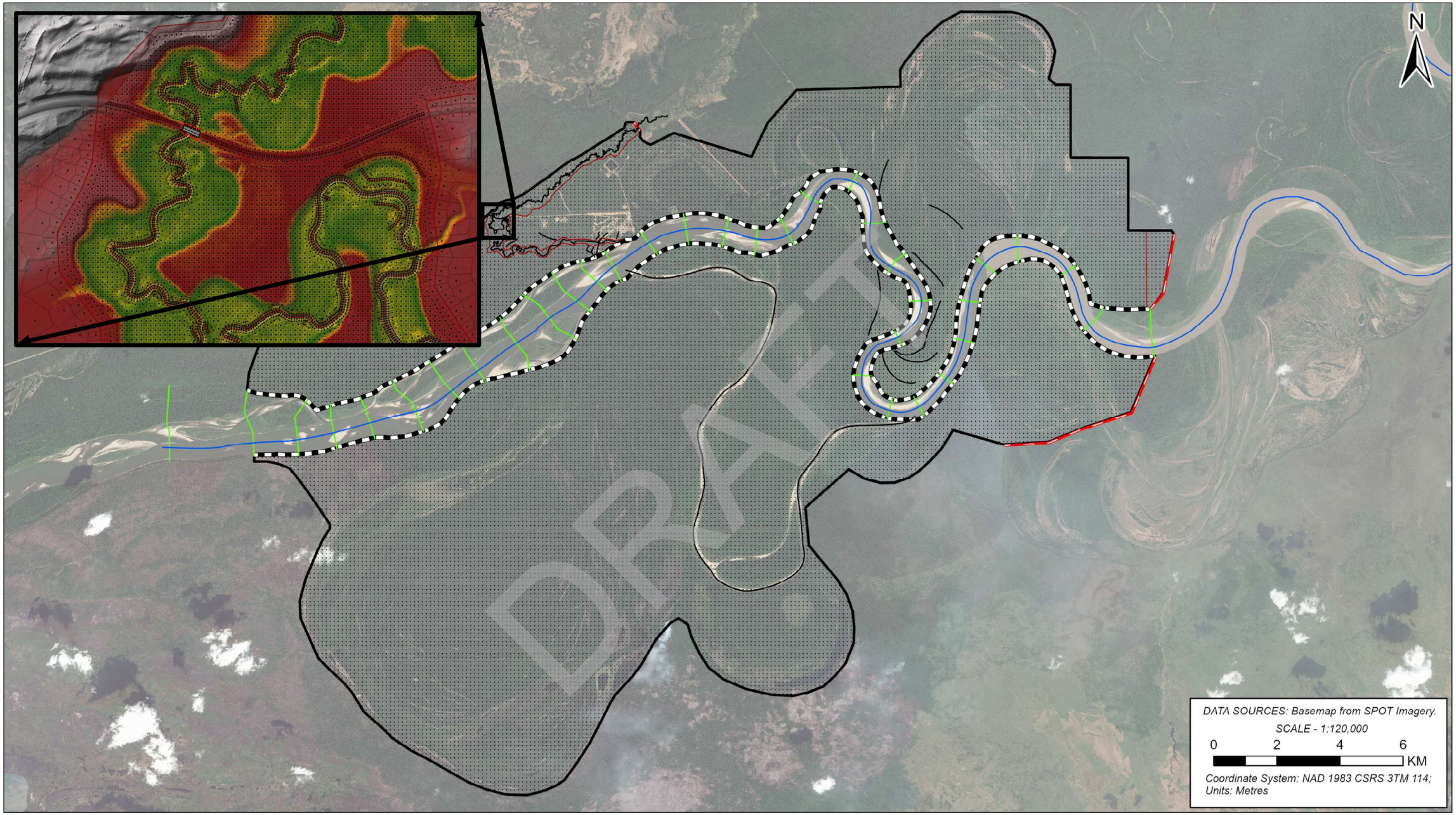
Notes:
1. Blue shaded inundation extents were computed by the model ($Q_{Peace\ River}$ = 14,500 m^3/s; $Q_{Garden\ Creek}$ = 68.4 m^3/s).

GARDEN RIVER FLOOD STUDY

GARDEN CREEK BELOW HWY 58 SHOWING COMPUTED FLOOD PATHS

Job: 1009251	*Date: May-2026*	*FIGURE 3*

Classification: Public



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Canada
nhc

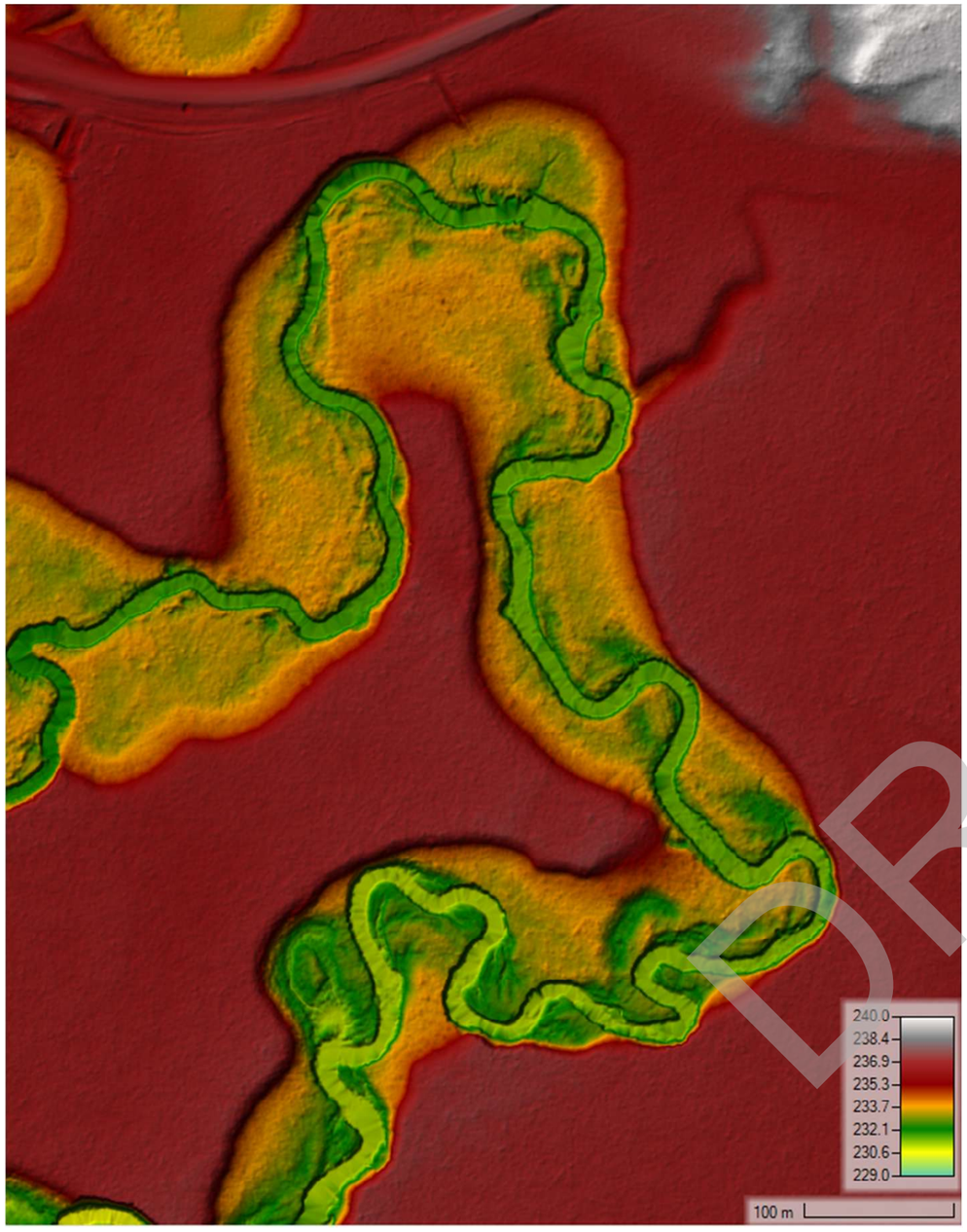
- Model 1D Reach
- Model 1D Cross Sections
- Model 2D Breaklines
- 2D Model Boundary
- Lateral Structures
- 2D Areas
- 2D Model Refinement Region

GARDEN RIVER FLOOD STUDY

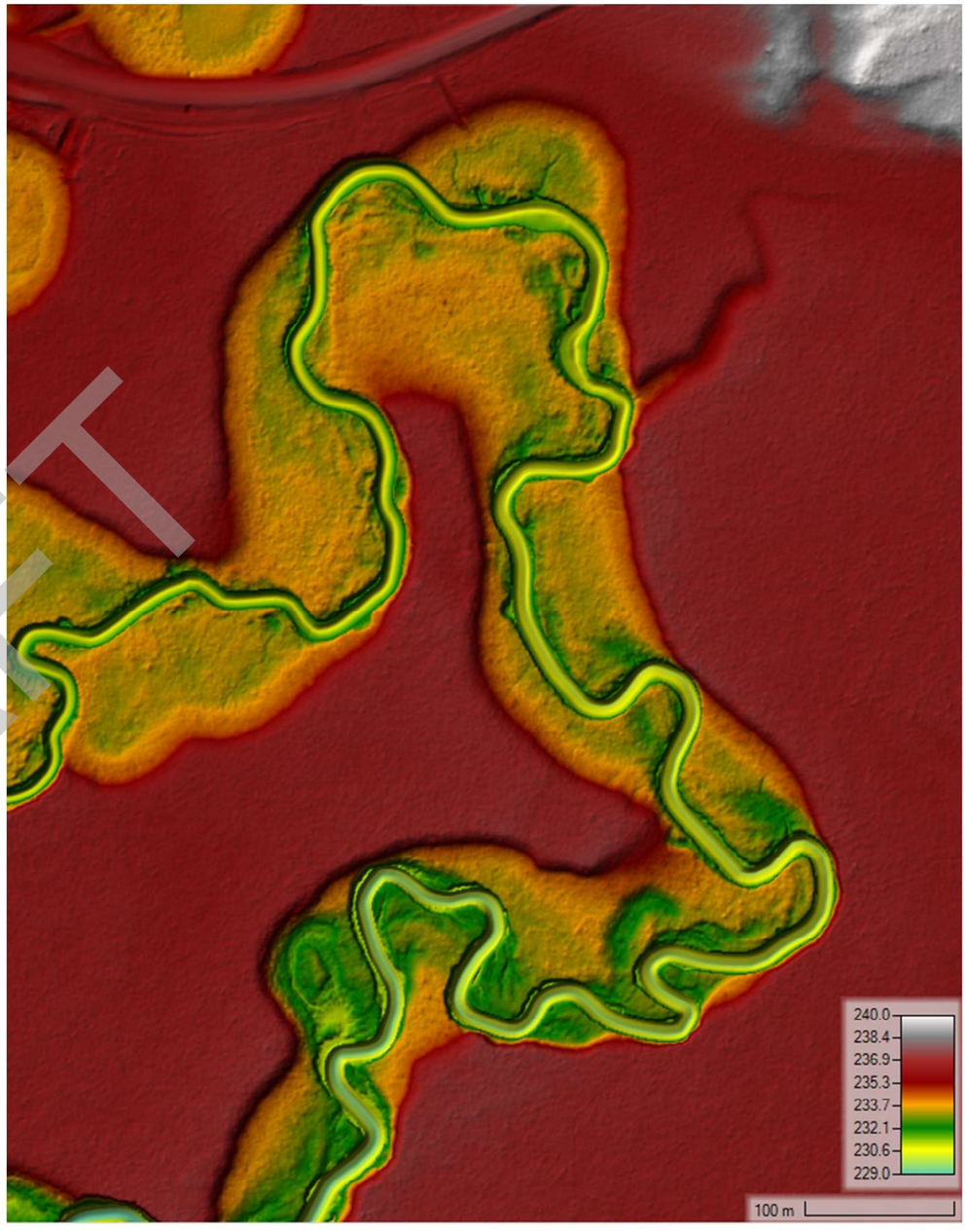
HYDRAULIC MODEL ELEMENTS

Job: 1009251	Date: May-2026	FIGURE 4

Classification: Public



(a) bare-earth-terrain



(b) 2D-model terrain

DRAFT

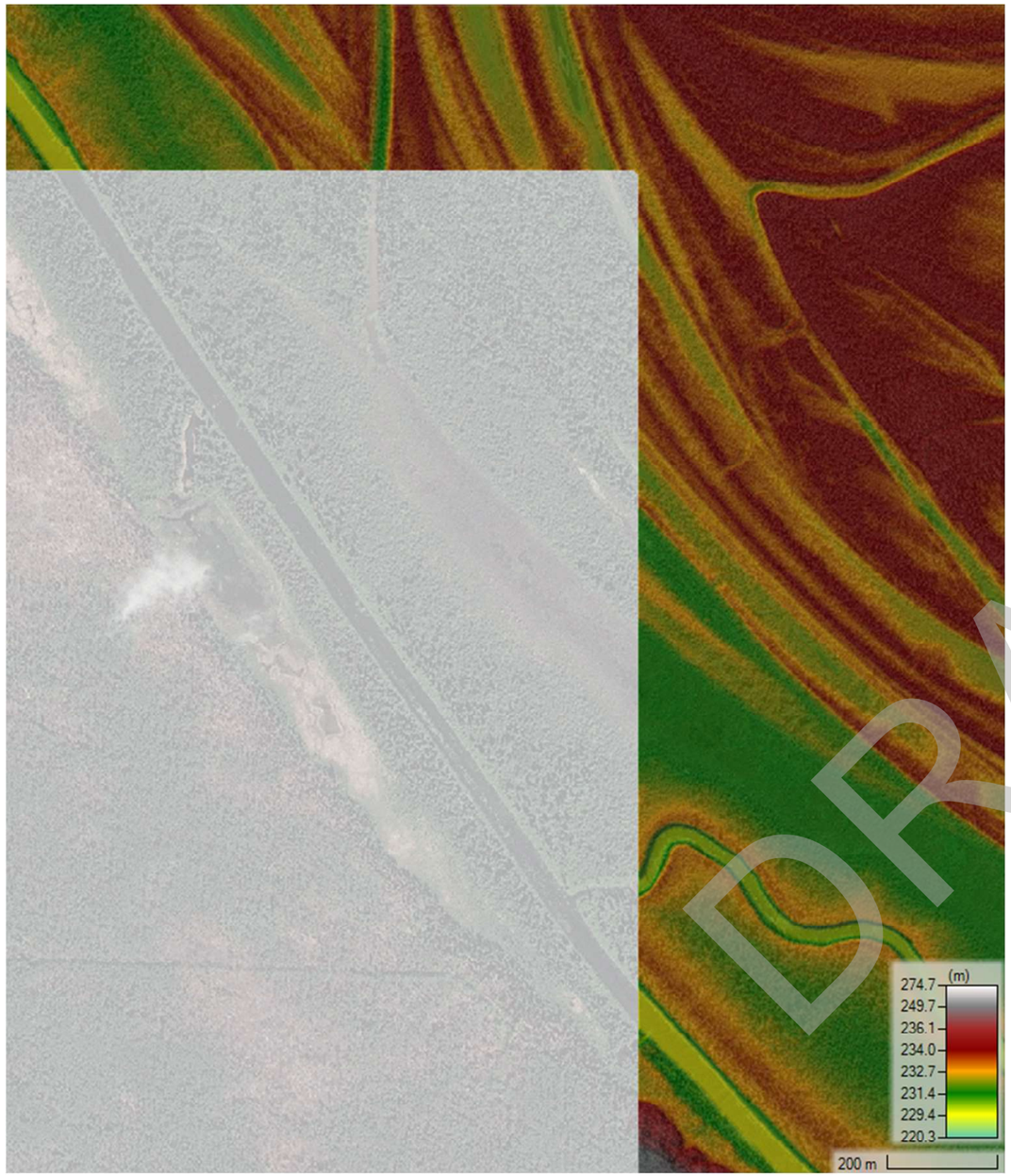
Notes:
1. The bare-earth terrain is derived from LiDAR bare-earth DTM provided by EPA. The 2D model terrain is based on a modified version of the DTM incorporating synthesized channels within the 2D domain and approximated terrain in areas outside of EPA's LiDAR coverage. This figure shows the synthesized Garden Creek channel within the 2D model terrain .

GARDEN RIVER FLOOD STUDY

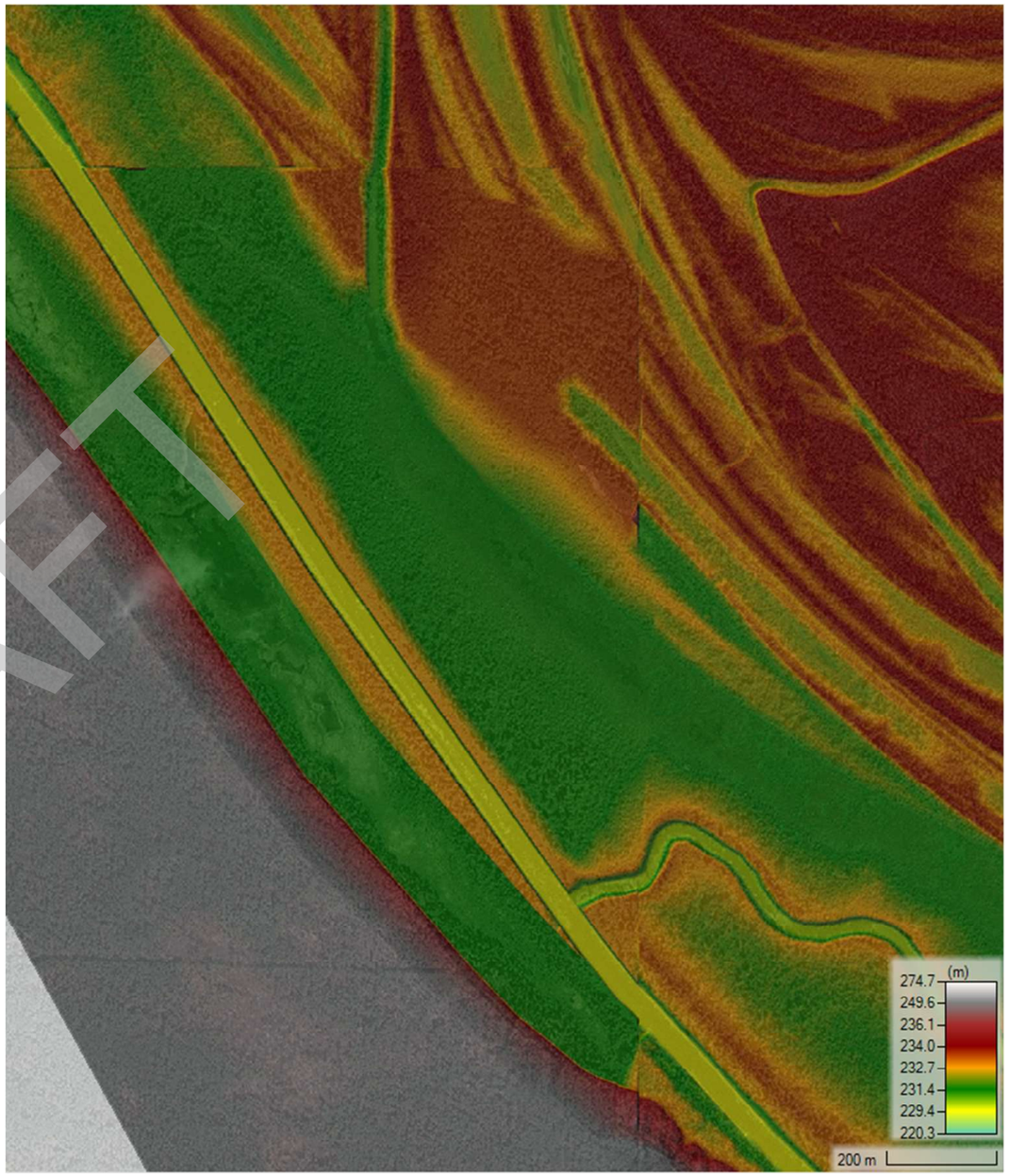
ILLUSTRATIVE COMPARISON OF TERRAIN MODIFICATIONS FOR GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 5

Classification: Public



(a) bare-earth-terrain



(b) 2D-model terrain

DRAFT

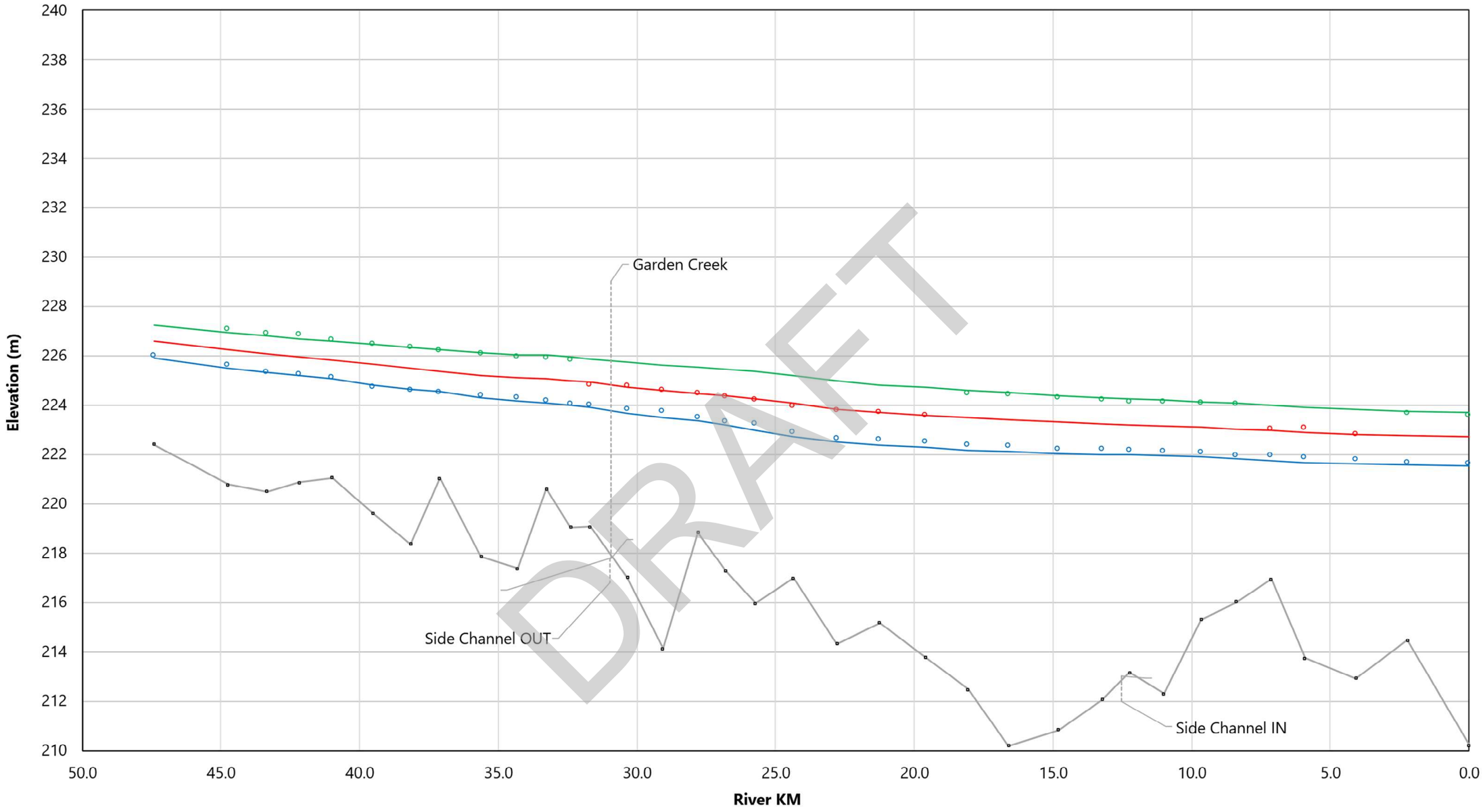
Notes:
1. Both terrains are overlain by a transparent layer of SPOT Imagery.
2. The bare-earth terrain is derived from LiDAR bare-earth DTM provided by EPA. The 2D model terrain is based on a modified version of the DTM incorporating synthesized channels within the 2D domain and approximated terrain in areas outside of EPA's LiDAR coverage. This figure shows the approximated terrain area at the southwest corner of the terrain based off inspection of the DTM bounds and SPOT Imagery.

GARDEN RIVER FLOOD STUDY

ILLUSTRATIVE COMPARISON OF TERRAIN MODIFICATIONS TO EXTEND THE DTM COVERAGE

Job: 1009251	Date: May-2026	FIGURE 6

Classification: Public



Surveyed Bed
08 OCT 2024 Surveyed
08 OCT 2024 Calibration Profile
27 MAY 2024 LiDAR Surface
27 MAY 2024 Calibration Profile
13 JUN 2024 LiDAR Surface
13 JUN 2024 Calibration Profile

GARDEN RIVER FLOOD STUDY

OPEN WATER CALIBRATION PROFILES PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 7

Classification: Public



Notes:
1. Background imagery obtained from the Copernicus Browser (July 6, 2020, Sentinel-2).
2. Blue shaded areas depict the inundation extents from a snapshot of a hydraulic model simulation of the July 2020 flood event, based on a hydrograph derived from the HEC-ResSim routing model ($Q_{Peace\ River}$ = 11,056 m^3/s; $Q_{Garden\ Creek}$ = 16.8 m^3/s).

GARDEN RIVER FLOOD STUDY

JULY 6, 2020, OPEN WATER FLOODING COMPARISON

Job: 1009251	Date: May-2026	FIGURE 8

Classification: Public



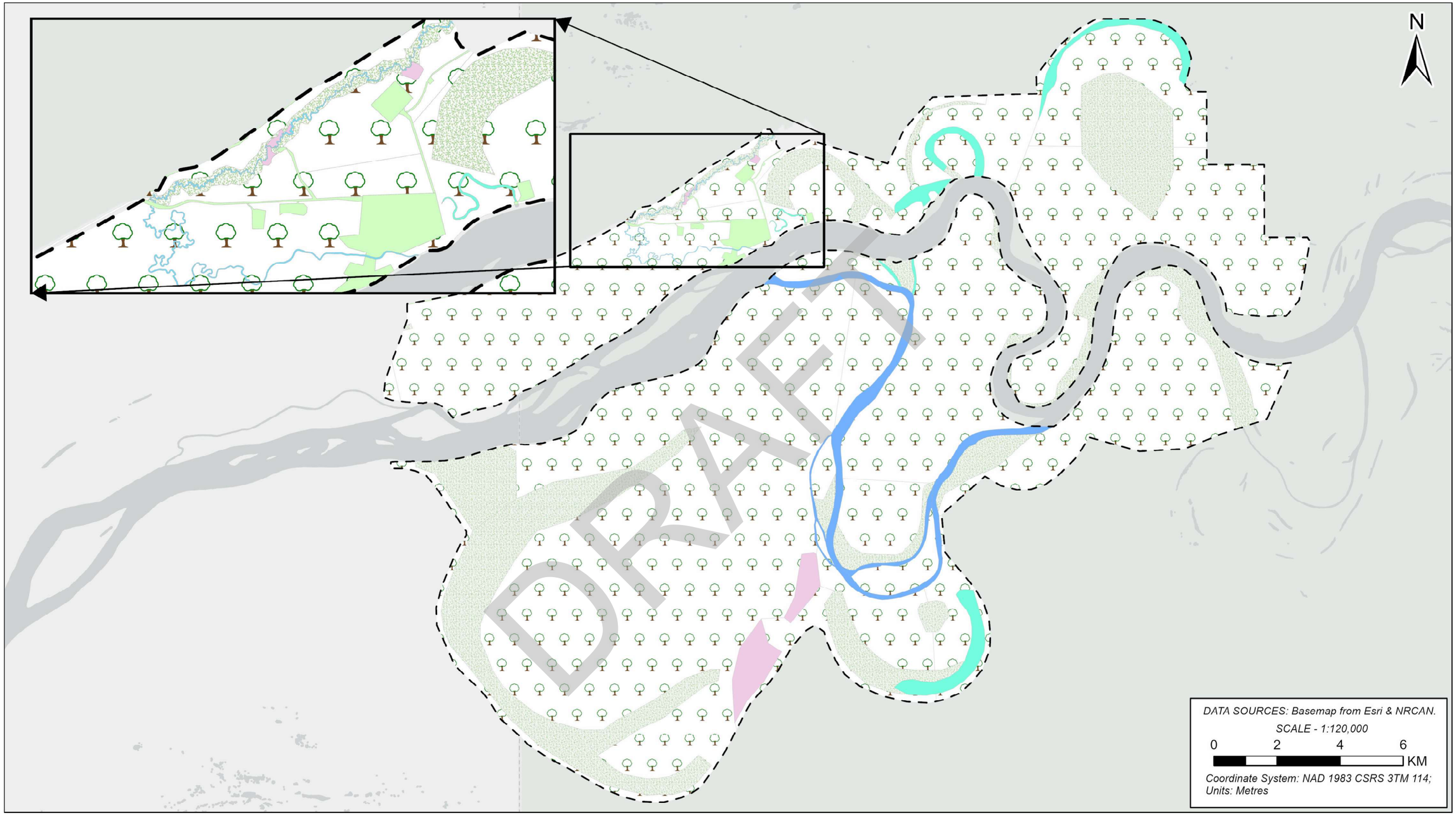
Notes:
1. Background imagery obtained from the Copernicus Browser (July 8, 2020, Sentinel-2).
2. Blue shaded areas depict the inundation extents from a snapshot of a hydraulic model simulation of the July 2020 flood event, based on a hydrograph derived from the HEC-ResSim routing model ($Q_{Peace\ River}$ = 11,165 m^3/s; $Q_{Garden\ Creek}$ = 16.8 m^3/s).

GARDEN RIVER FLOOD STUDY

JULY 8, 2020, OPEN WATER FLOODING COMPARISON

Job: 1009251	Date: May-2026	FIGURE 9

Classification: Public



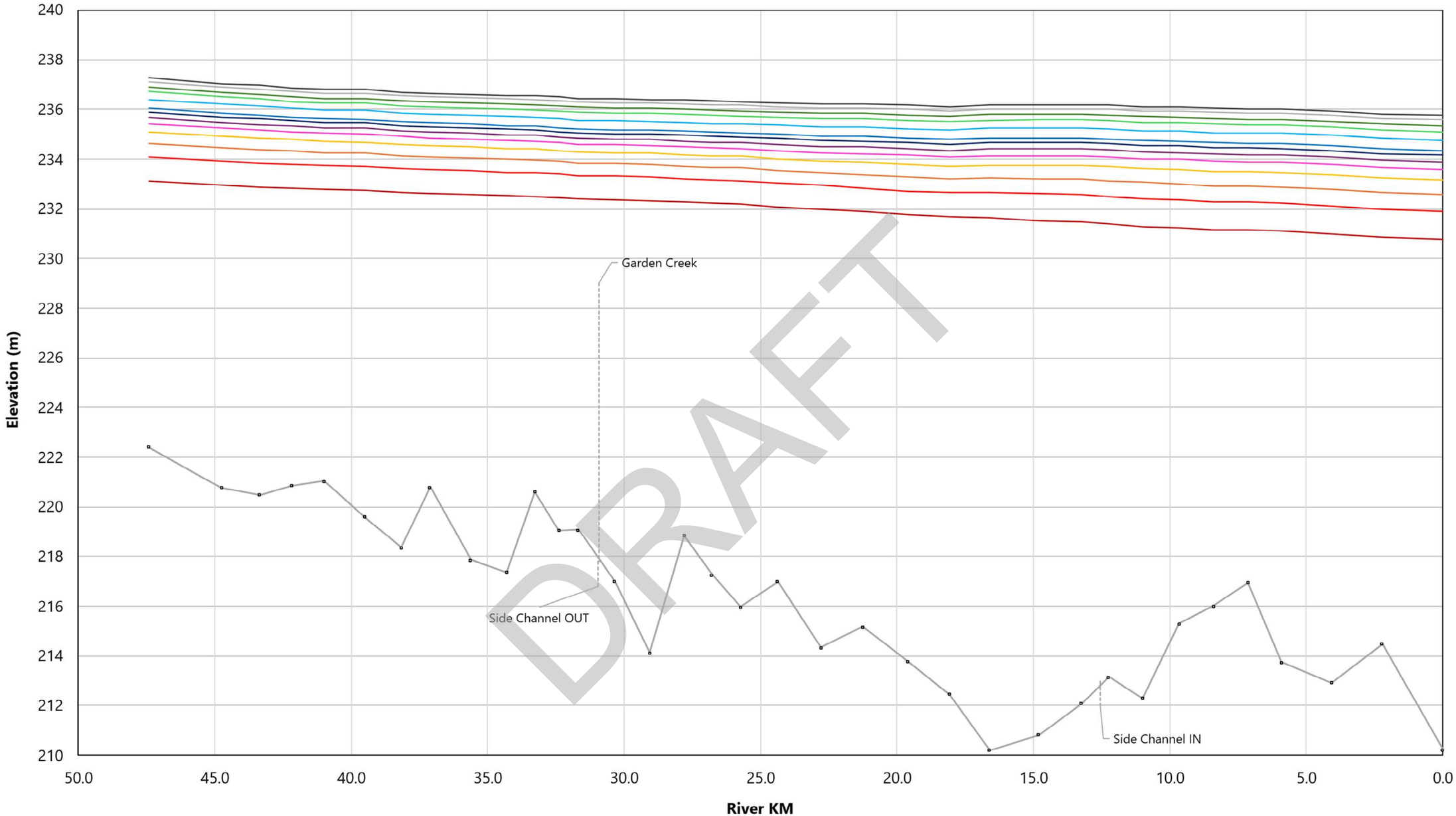
2D Model Domain
Peace River side channel (n = 0.026)
Open water (n = 0.035)
Garden Creek channel (n = 0.040)
Wetland (n = 0.050)
Shrubs (n = 0.050)
Developed - low density ((n = 0.055)
Trees (n = 0.060)

GARDEN RIVER FLOOD STUDY

LAND USE AREAS FOR MANNING'S ROUGHNESS

Job: 1009251	Date: May-2026	FIGURE 10

Classification: Public



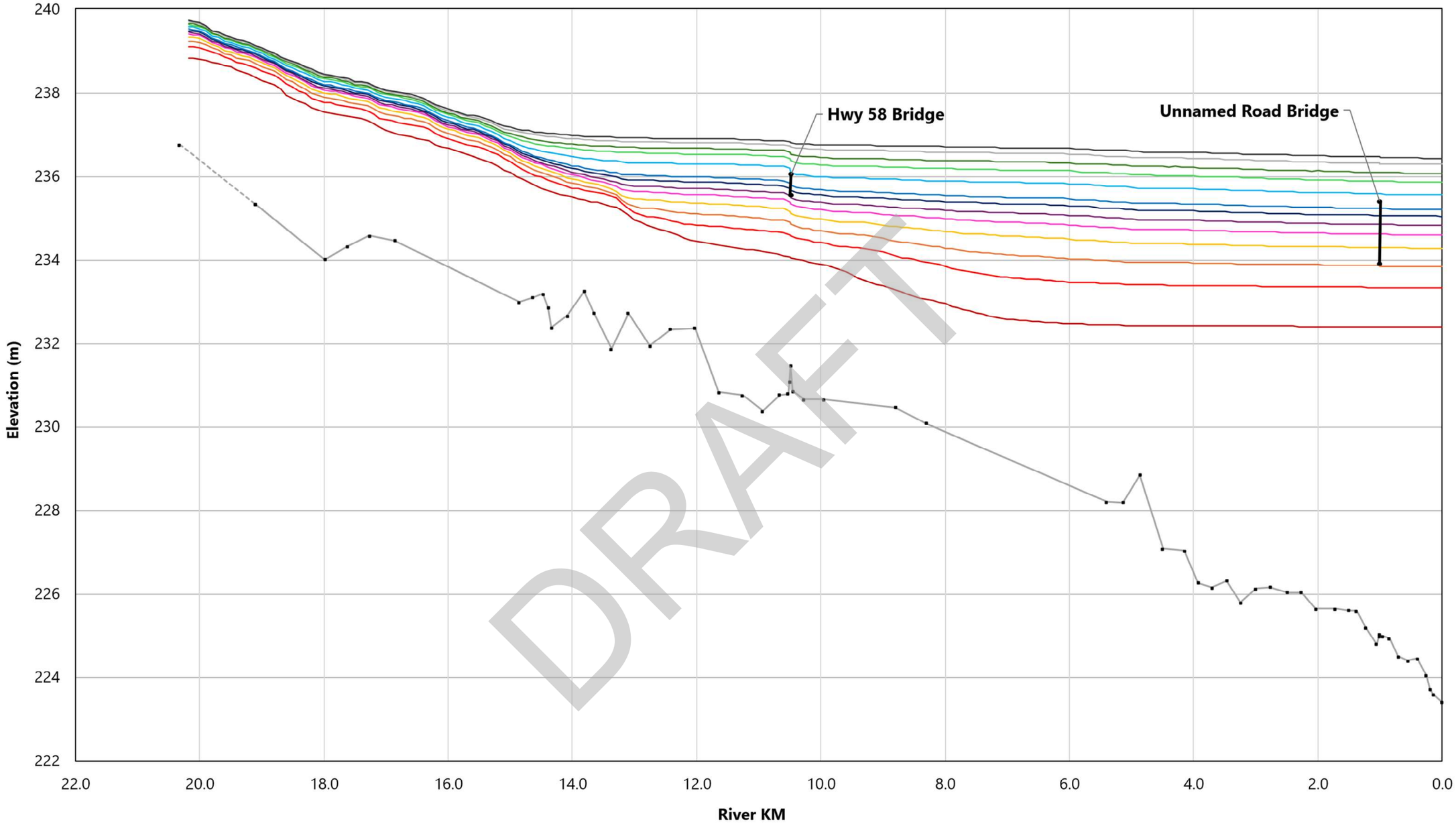
Surveyed Bed
1:2 Flood
1:5 Flood
1:10 Flood
1:20 Flood
1:35 Flood
1:50 Flood
1:75 Flood
1:100 Flood
1:200 Flood
1:350 Flood
1:500 Flood
1:750 Flood
1:1000 Flood

GARDEN RIVER FLOOD STUDY

OPEN WATER FLOOD FREQUENCY PROFILES
PEACE RIVER

Job: 1009251	Date: May-2026	*FIGURE 11*

Classification: Public



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Surveyed Bed
Assumed Bed (Extrapolated)
1:2 Flood
1:5 Flood
1:10 Flood
1:20 Flood
1:35 Flood
1:50 Flood
1:75 Flood
1:100 Flood
1:200 Flood
1:350 Flood
1:500 Flood
1:750 Flood
1:1000 Flood

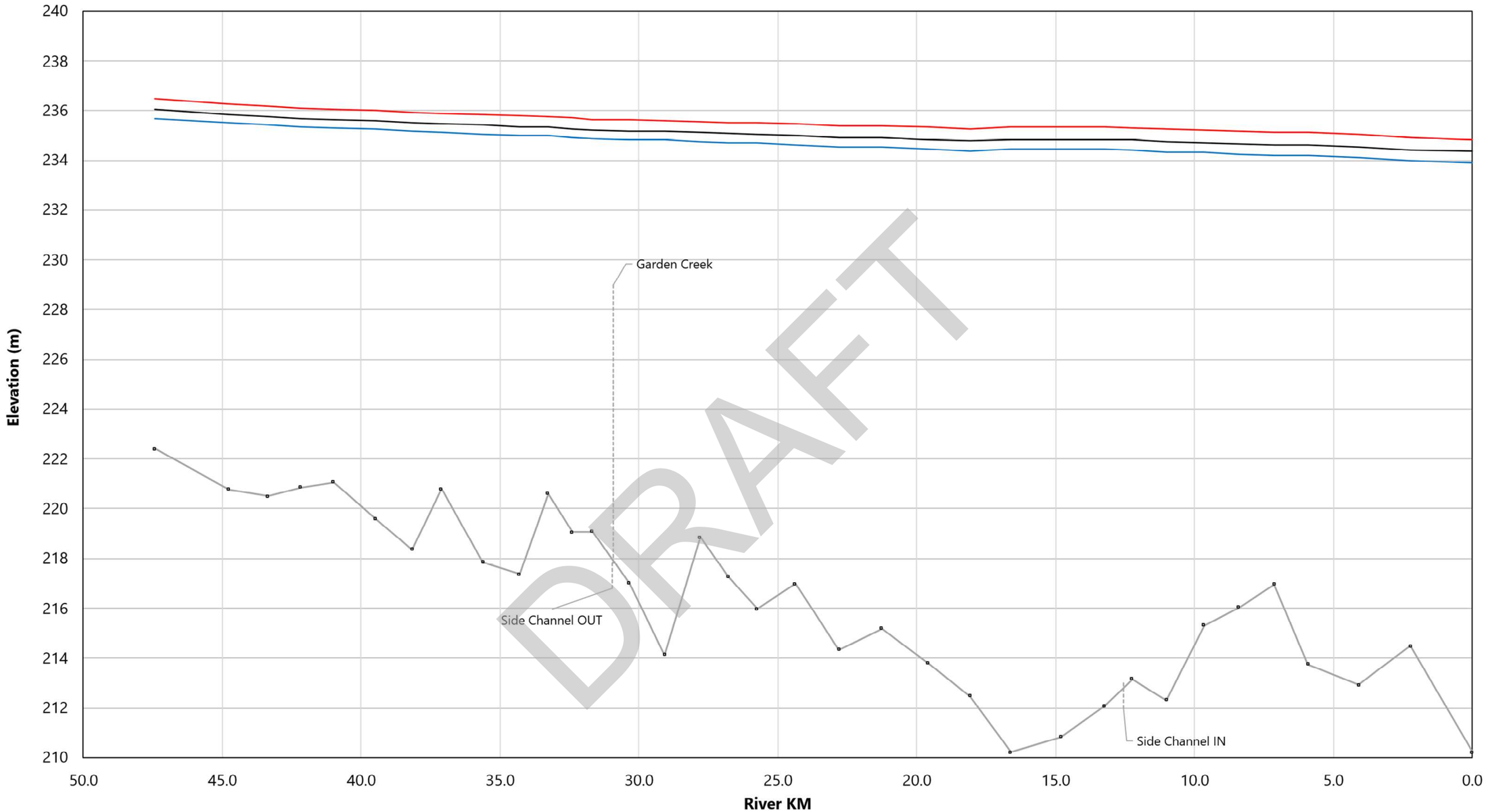
Bridges
high chord
low chord

GARDEN RIVER FLOOD STUDY

OPEN WATER FLOOD FREQUENCY PROFILES GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 12

Classification: Public



DRAFT

Surveyed Bed

1:100 Open Water Flood Baseline (Q = 18,200 cms)

Lower Limit (Q = 16,700 cms)

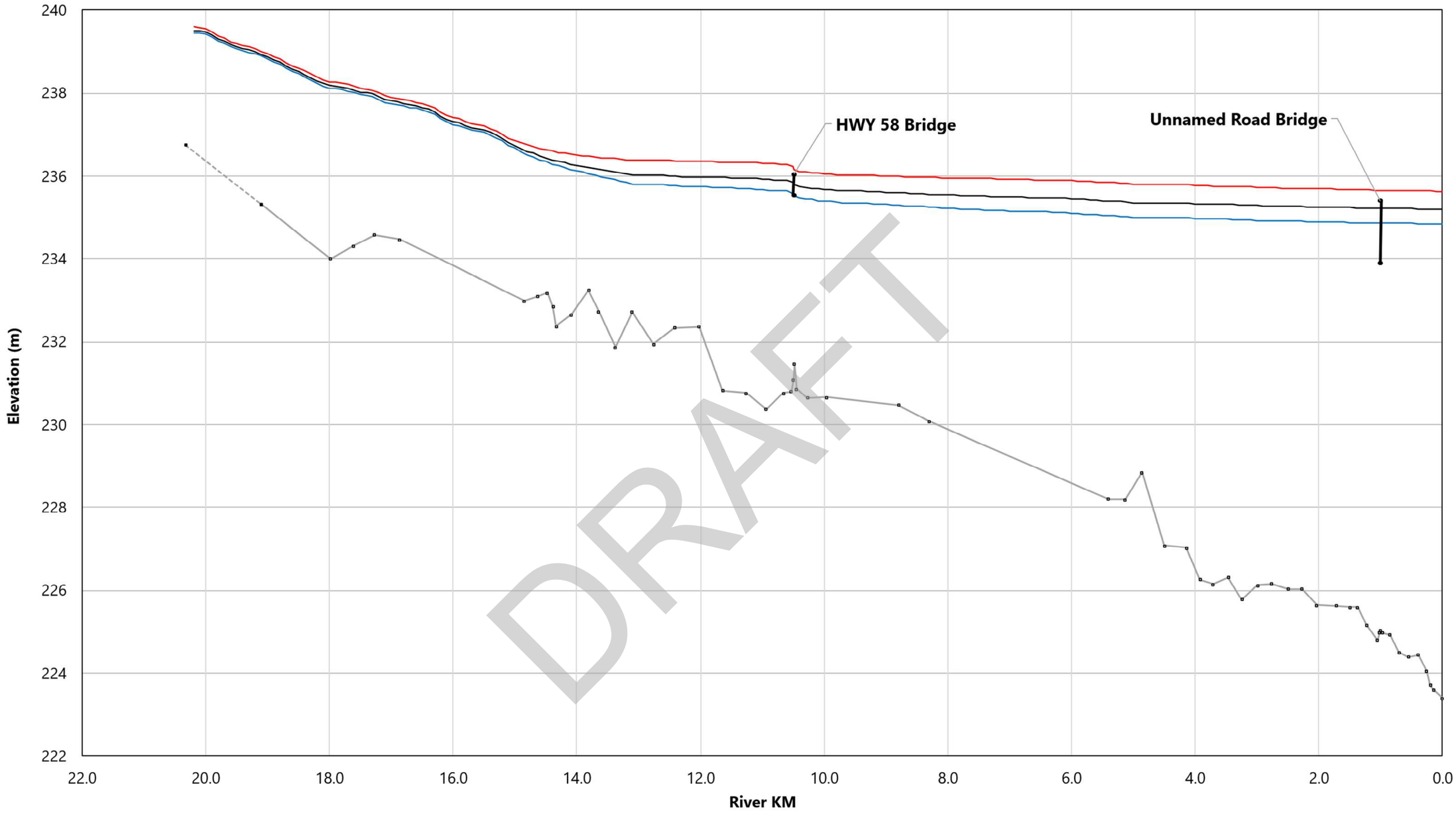
Upper Limit (Q = 20,300 cms)

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED UPSTREAM BOUNDARY DISCHARGE PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 13

Classification: Public



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Surveyed Bed

Assumed Bed (Extrapolated)

1:100 Open Water Flood Baseline (Q = 105 cms)

Lower Limit (Q = 92 cms)

Upper Limit (Q = 123 cms)

Bridges

high chord

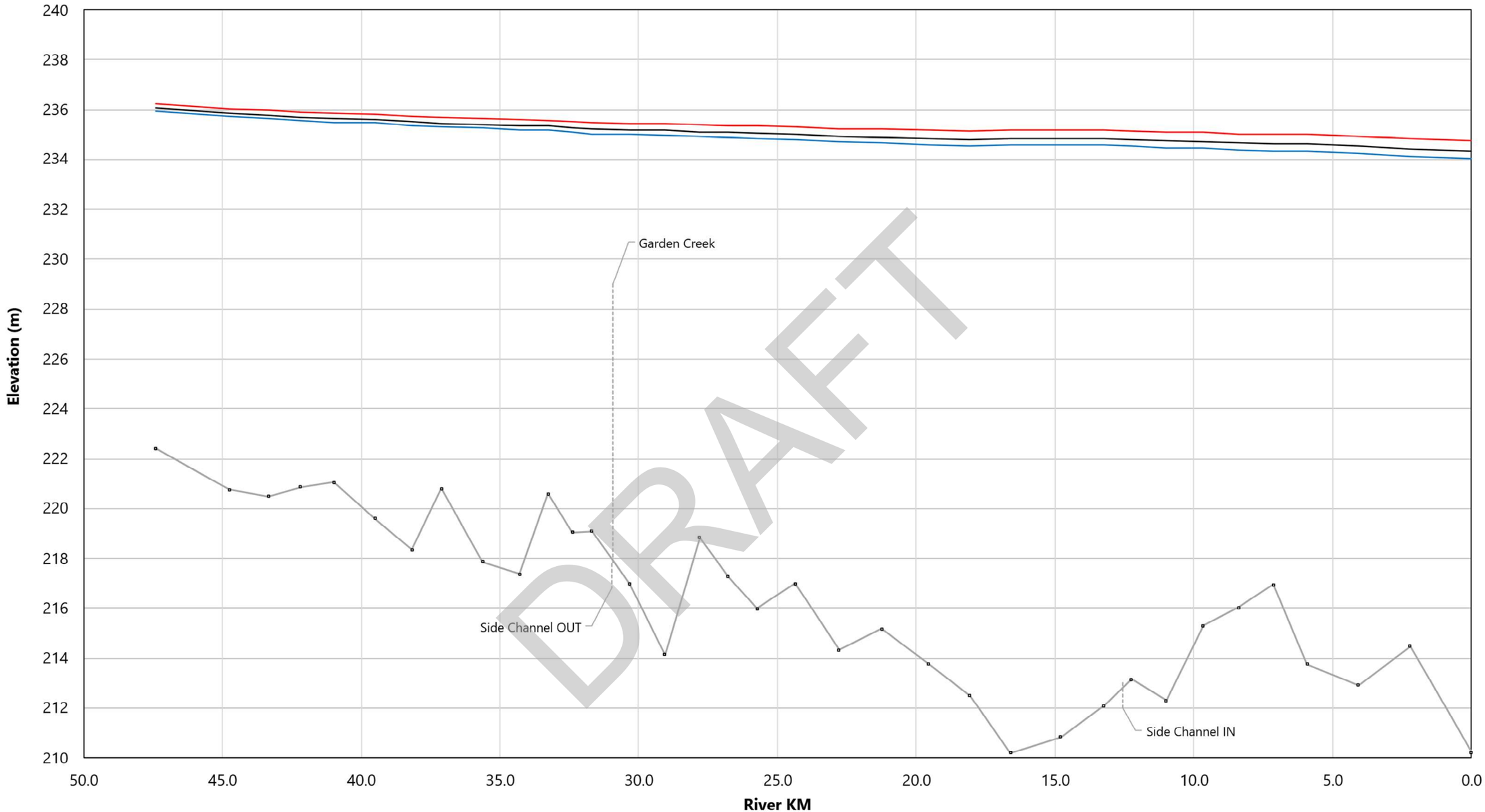
low chord

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED UPSTREAM BOUNDARY DISCHARGE GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 14

Classification: Public



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Surveyed Bed

1:100 Open Water Flood Baseline Rating Curve (Based on Normal Depth Slope = 0.000035)

Lower Rating Curve (Based on Normal Depth Slope = 0.000042)

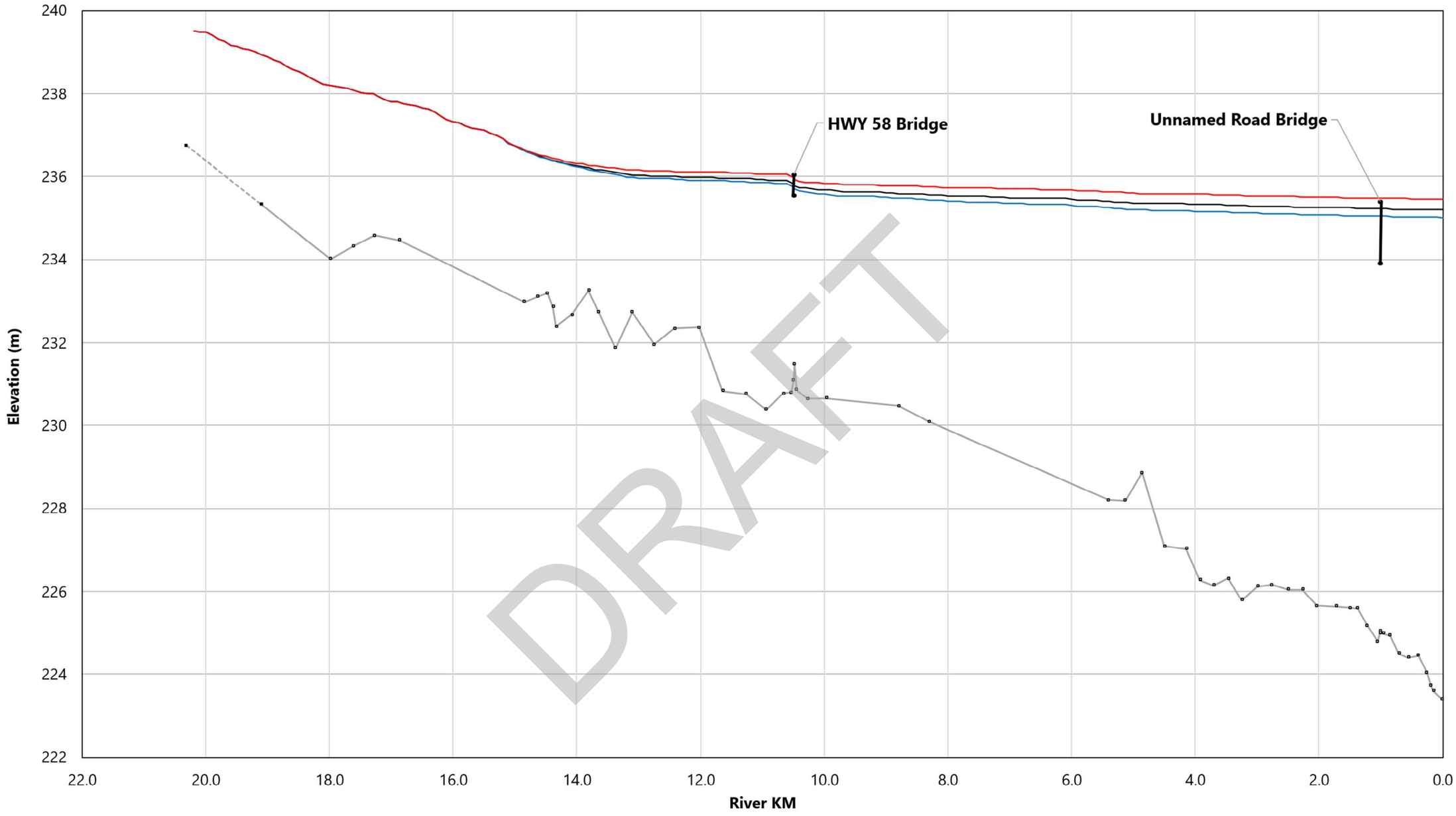
Higher Rating Curve (Based on Normal Depth Slope = 0.000028)

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED DOWNSTREAM BOUNDARY CONDITION PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 15

Classification: Public



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Surveyed Bed
Assumed Bed (Extrapolated)
1:100 Open Water Flood Baseline Rating Curve (Based on Normal Depth Slope = 0.000035)
Lower Rating Curve (Based on Normal Depth Slope = 0.000042)
Higher Rating Curve (Based on Normal Depth Slope = 0.000028)

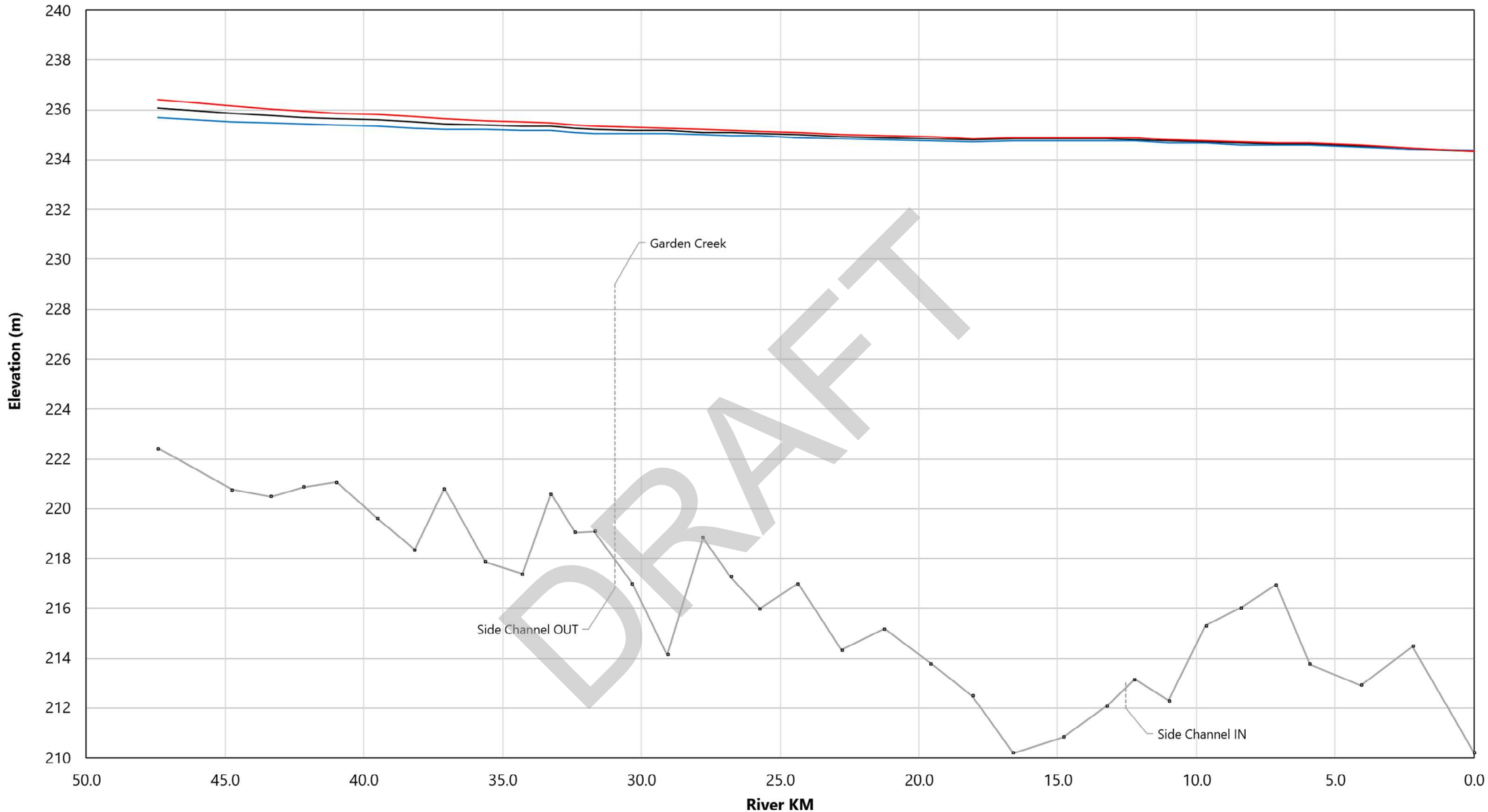
Bridges
high chord
low chord

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED DOWNSTREAM BOUNDARY CONDITION GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 16

Classification: Public



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Surveyed Bed

1:100 Open Water Flood Baseline Roughness

Lower Channel Roughness (n - 20%)

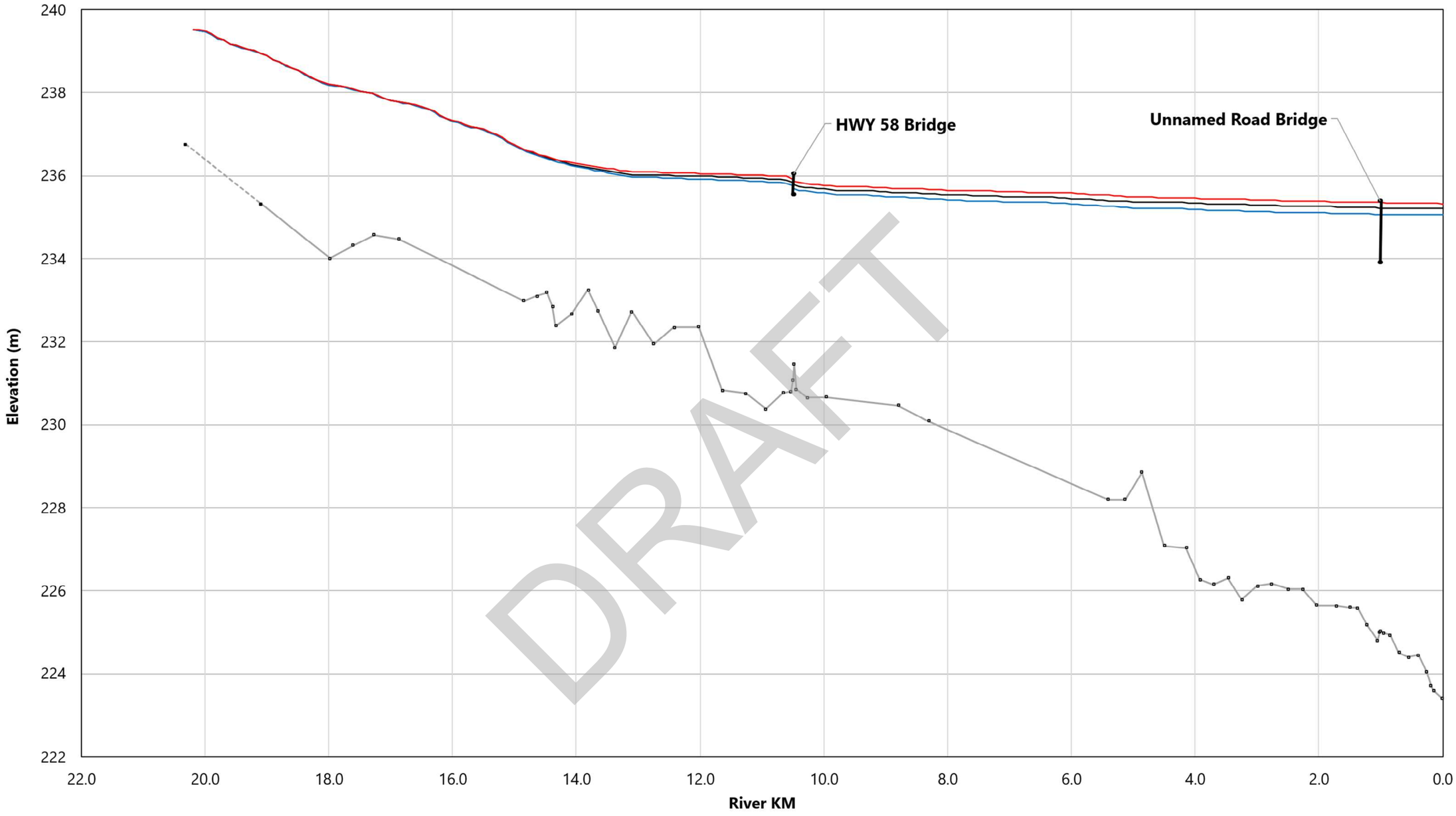
Higher Channel Roughness (n + 20%)

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED CHANNEL ROUGHNESS PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 17

Classification: Public



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Canada
nhc

Surveyed Bed
Assumed Bed (Extrapolated)
1:100 Open Water Flood Baseline Roughness
Lower Channel Roughness (n - 20%)
Higher Channel Roughness (n + 20%)

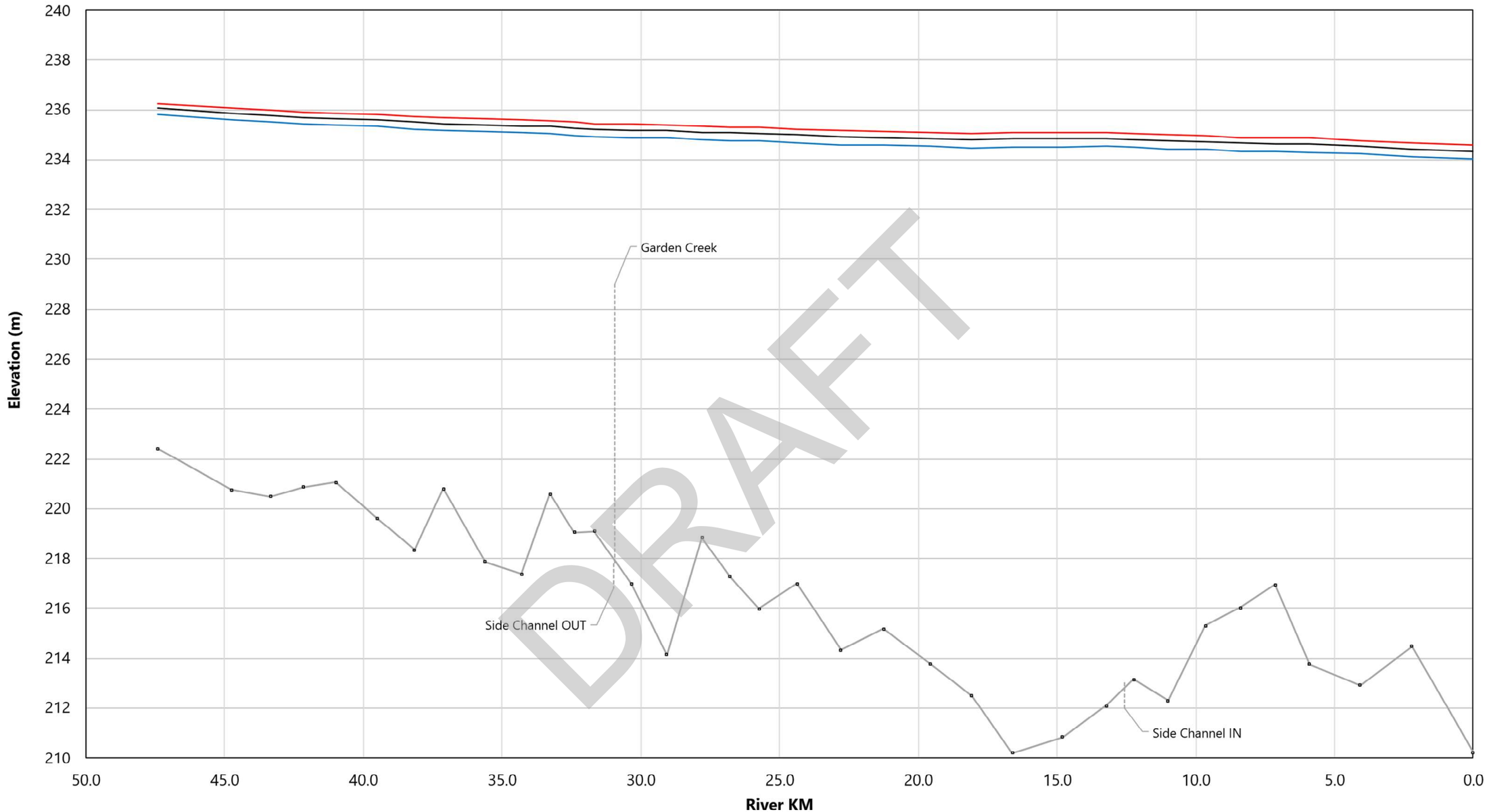
Bridges
high chord
low chord

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED CHANNEL ROUGHNESS GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 18

Classification: Public



DRAFT

Surveyed Bed

1:100 Open Water Flood Baseline Roughness

Lower Overbank Roughness (n - 20%)

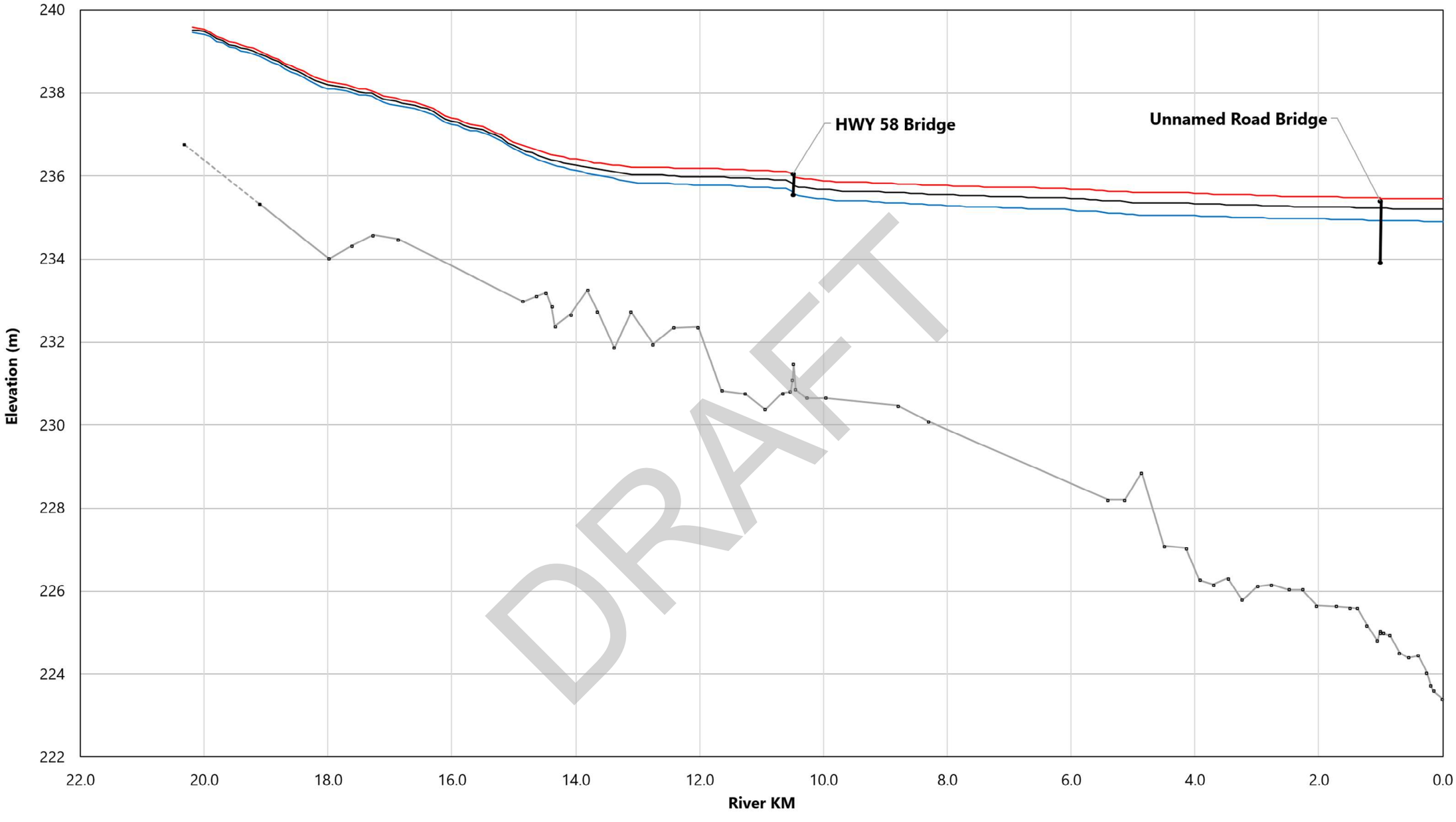
Higher Overbank Roughness (n + 20%)

GARDEN RIVER FLOOD STUDY

SENSITIVITY TO VARIED OVERBANK ROUGHNESS PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 19

Classification: Public



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Canada
nhc

Surveyed Bed
Assumed Bed (Extrapolated)
1:100 Open Water Flood Baseline Roughness
Lower Overbank Roughness (n - 20%)
Higher Overbank Roughness (n + 20%)

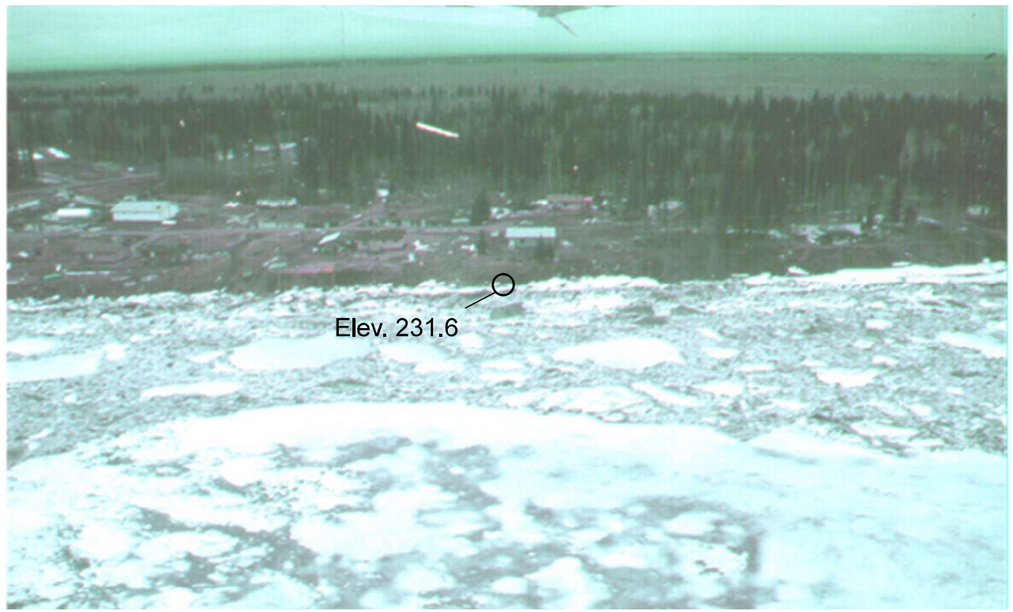
Bridges
high chord
low chord

GARDEN RIVER FLOOD STUDY

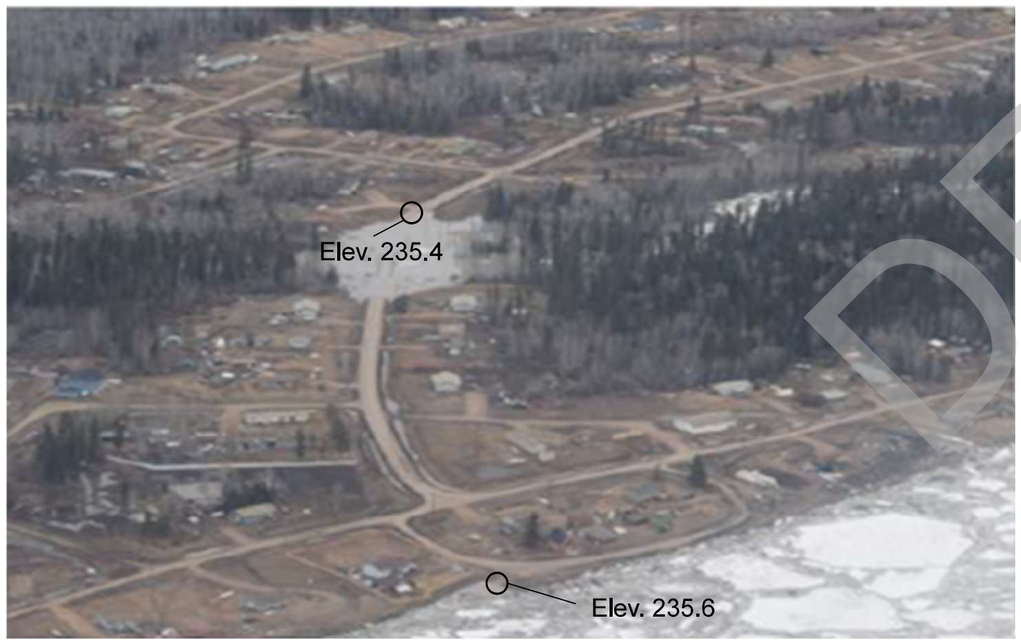
SENSITIVITY TO VARIED OVERBANK ROUGHNESS GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 20

Classification: Public



- 1996 Ice Jam Flood – Looking at the community of Garden River near River Station 69865 of the Peace River.
- Photo taken by Parks Canada on April 30, 1996.
- Elevation estimated from DTM at location indicted by arrow.



- 2020 Ice Jam Flood – Looking at the community of Garden River near River Station 70070 of the Peace River.
- Photo taken by Parks Canada on April 30, 2020.
- Elevations estimated from DTM at location indicted by arrow.

DRAFT

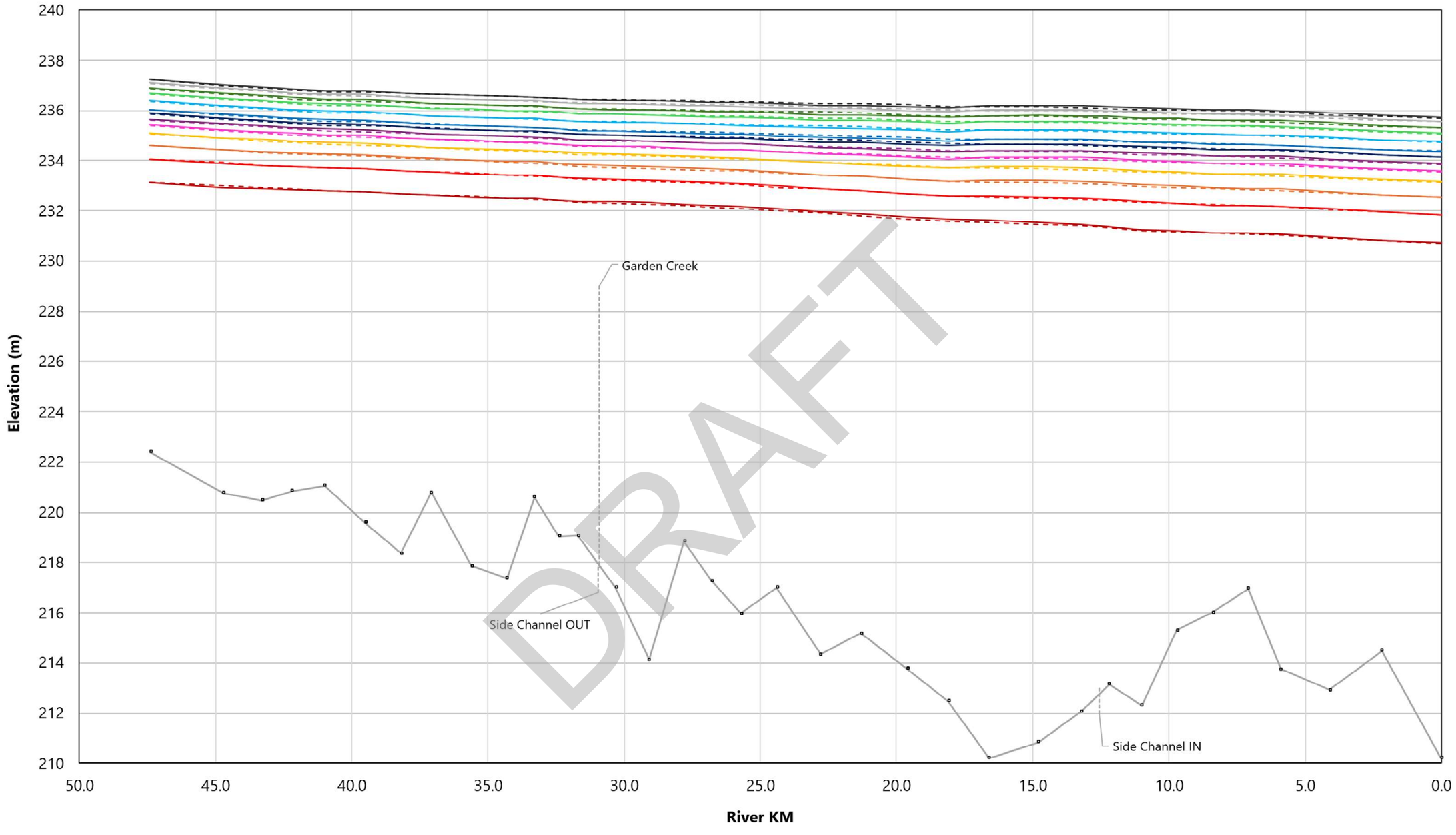
Alberta Canada nhc

GARDEN RIVER FLOOD STUDY

HIGHWATER MARKS ESTIMATED FROM PHOTOS

Job: 1009251	Date: May-2026	FIGURE 21

Classification: Public



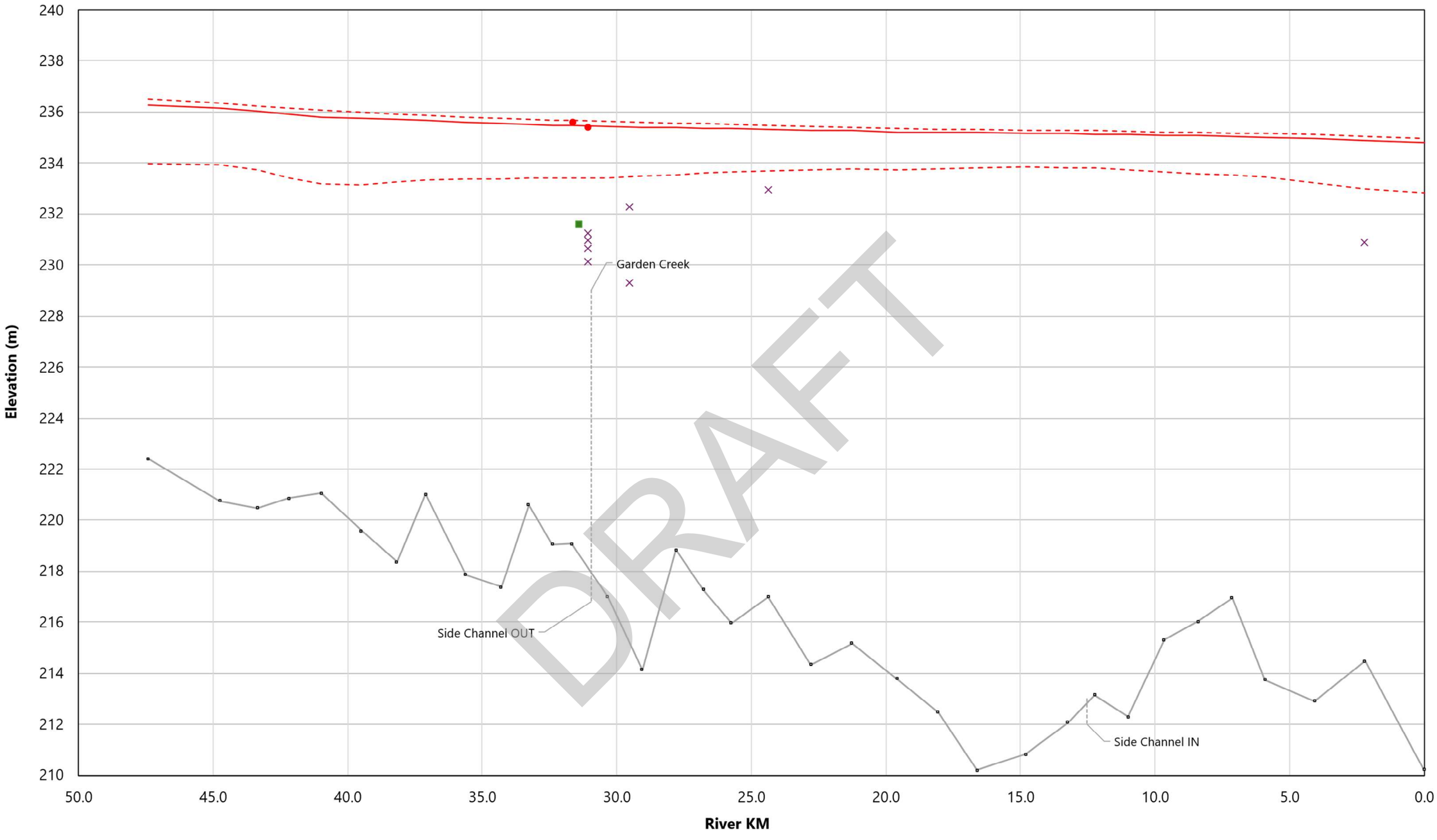
Surveyed Bed
1:2 Flood
1:5 Flood
1:10 Flood
1:20 Flood
1:35 Flood
1:50 Flood
1:75 Flood
1:100 Flood
1:200 Flood
1:350 Flood
1:500 Flood
1:750 Flood
1:1000 Flood
1:2 Approx
1:5 Approx
1:10 Approx
1:20 Approx
1:35 Approx
1:50 Approx
1:75 Approx
1:100 Approx
1:200 Approx
1:350 Approx
1:500 Approx
1:750 Approx
1:1000 Approx

GARDEN RIVER FLOOD STUDY

OPEN WATER DESIGN FLOOD PROFILES VS PROFILES BY 1D ICE ENHANCED MODEL OPEN WATER APPROXIMATION

Job: 1009251	Date: May-2026	FIGURE 22

Classification: Public



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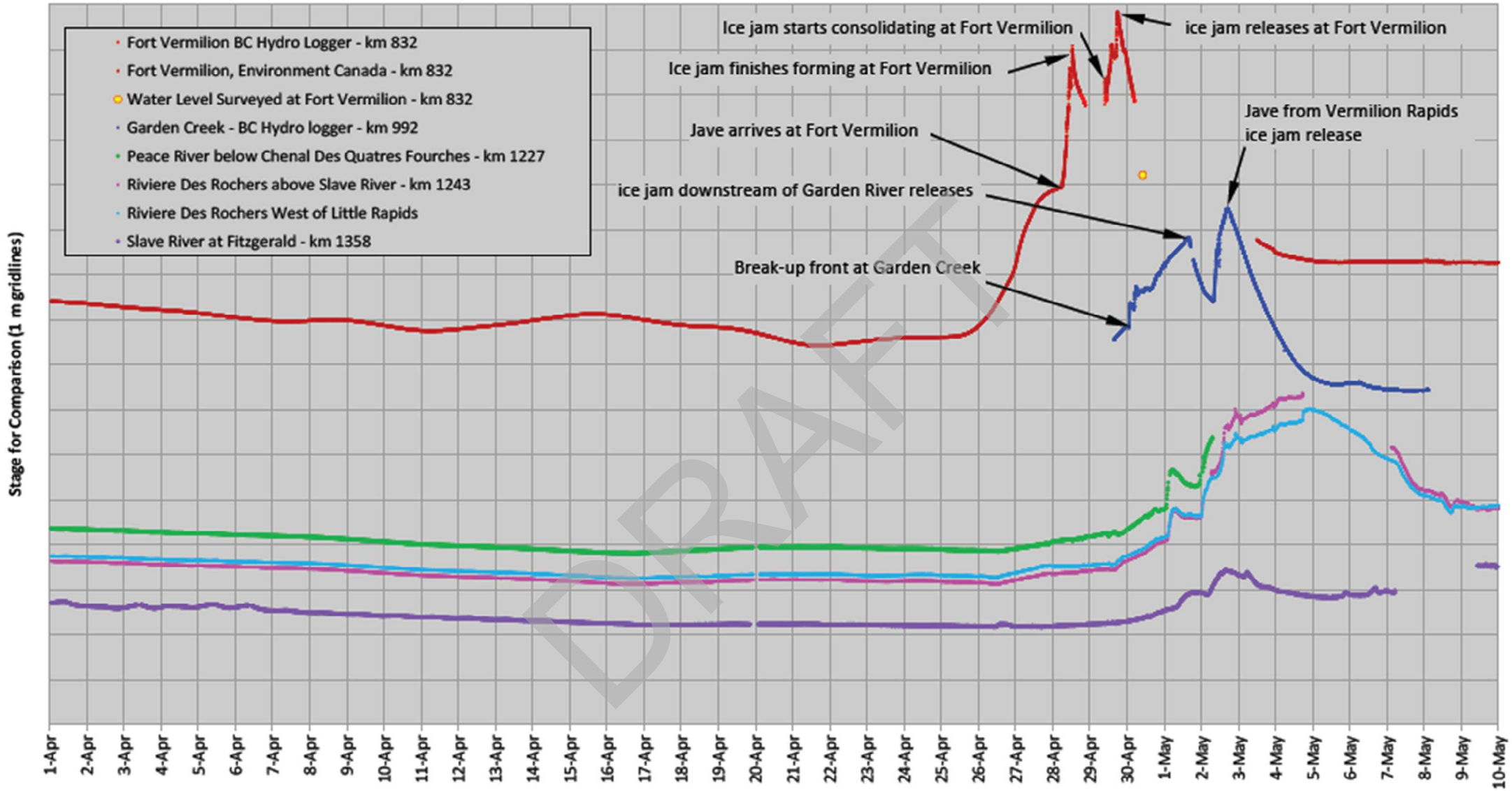
- Surveyed Bed
- 30 April 2020 Ice Jam Calibration (Q = 8296 cms)
- Top and Bottom of Ice 2020 Ice Jam Calibration
- Estimated 2020 HWM
- Estimated 1996 HWM
- Surveyed Tree Scars & Debris Piles

GARDEN RIVER FLOOD STUDY

ICE JAM CALIBRATION PROFILE 2020 ICE JAM

Job: 1009251	Date: May-2026	FIGURE 23

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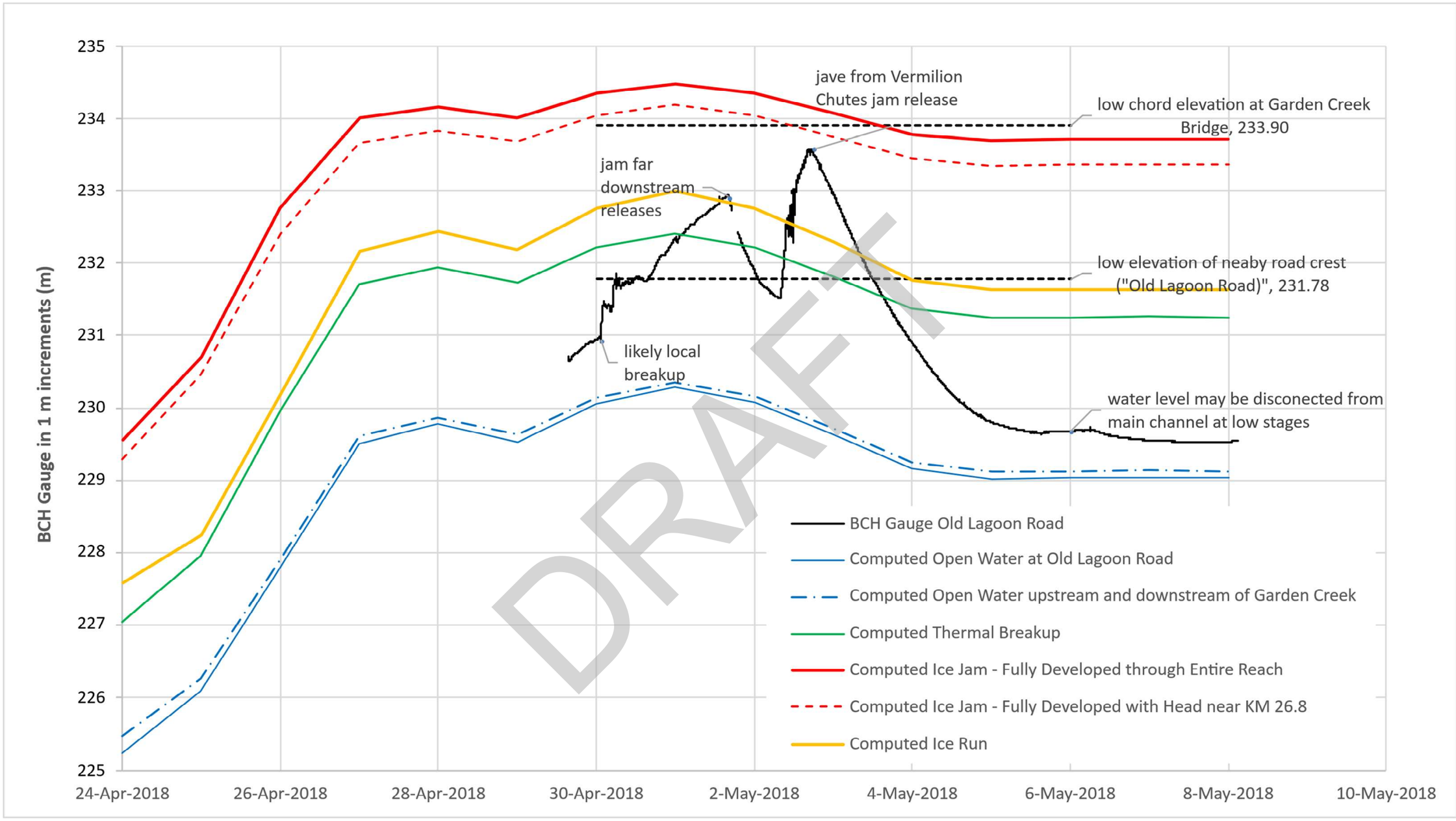
Notes: 1. Adapted from Jasek (2019).

GARDEN RIVER FLOOD STUDY

OBSERVED ICE-AFFECTED FLOOD LEVELS DURING 2018 BREAKUP

Job: 1009251	Date: May-2026	FIGURE 24

Classification: Public



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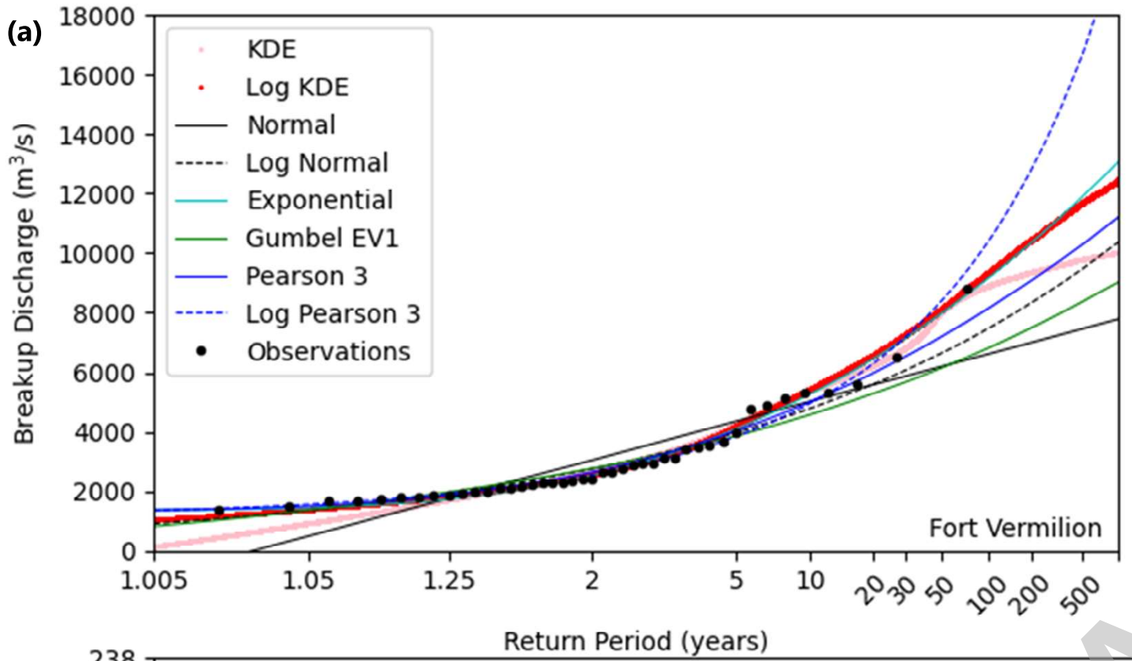
Notes:
1. The time series digitized from Jasek (2019) and shifted by eye for comparison.
2. Notes are transcribed from Jasek (2019).

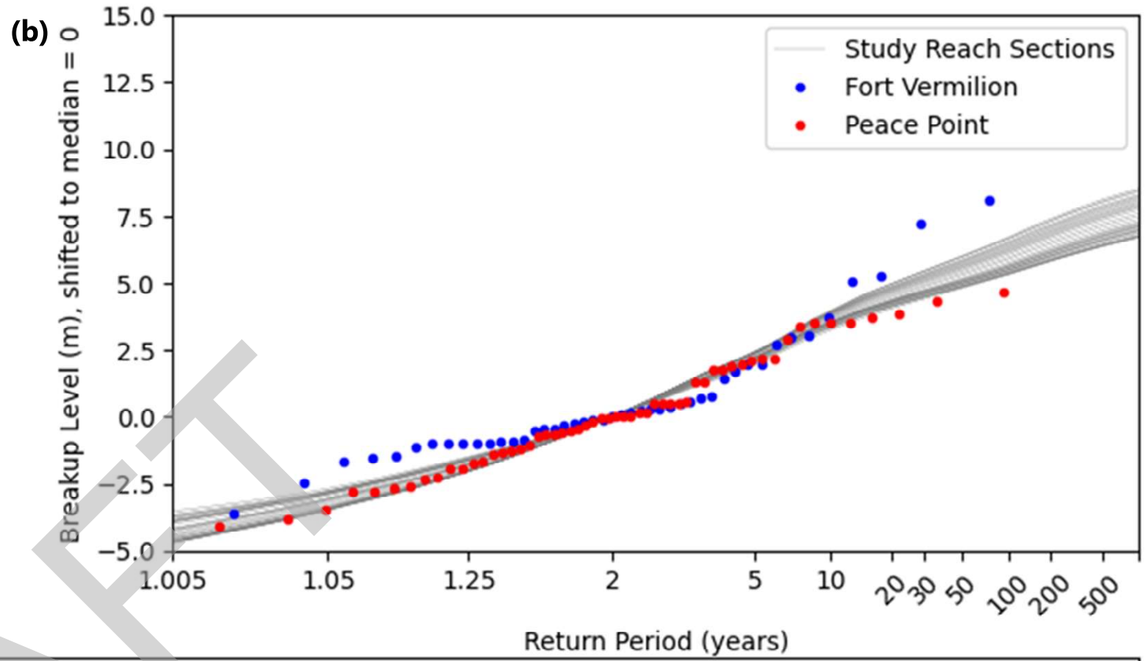
GARDEN RIVER FLOOD STUDY

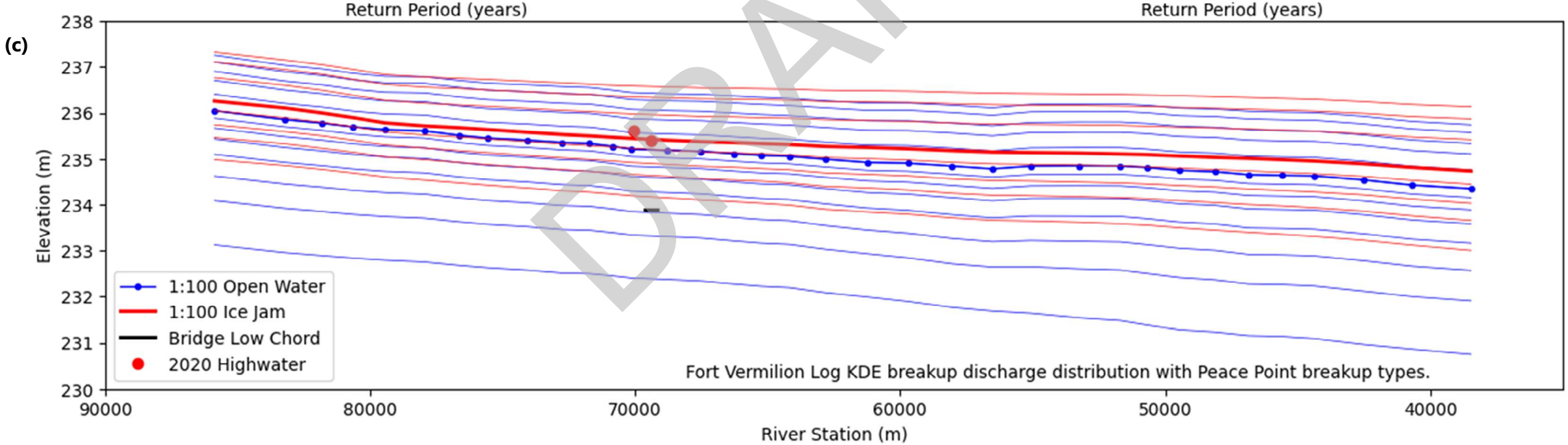
COMPUTED VS OBSERVED ICE-AFFECTED FLOOD LEVELS DURING 2018 BREAKUP

Job: 1009251	Date: May-2026	FIGURE 25

Classification: Public







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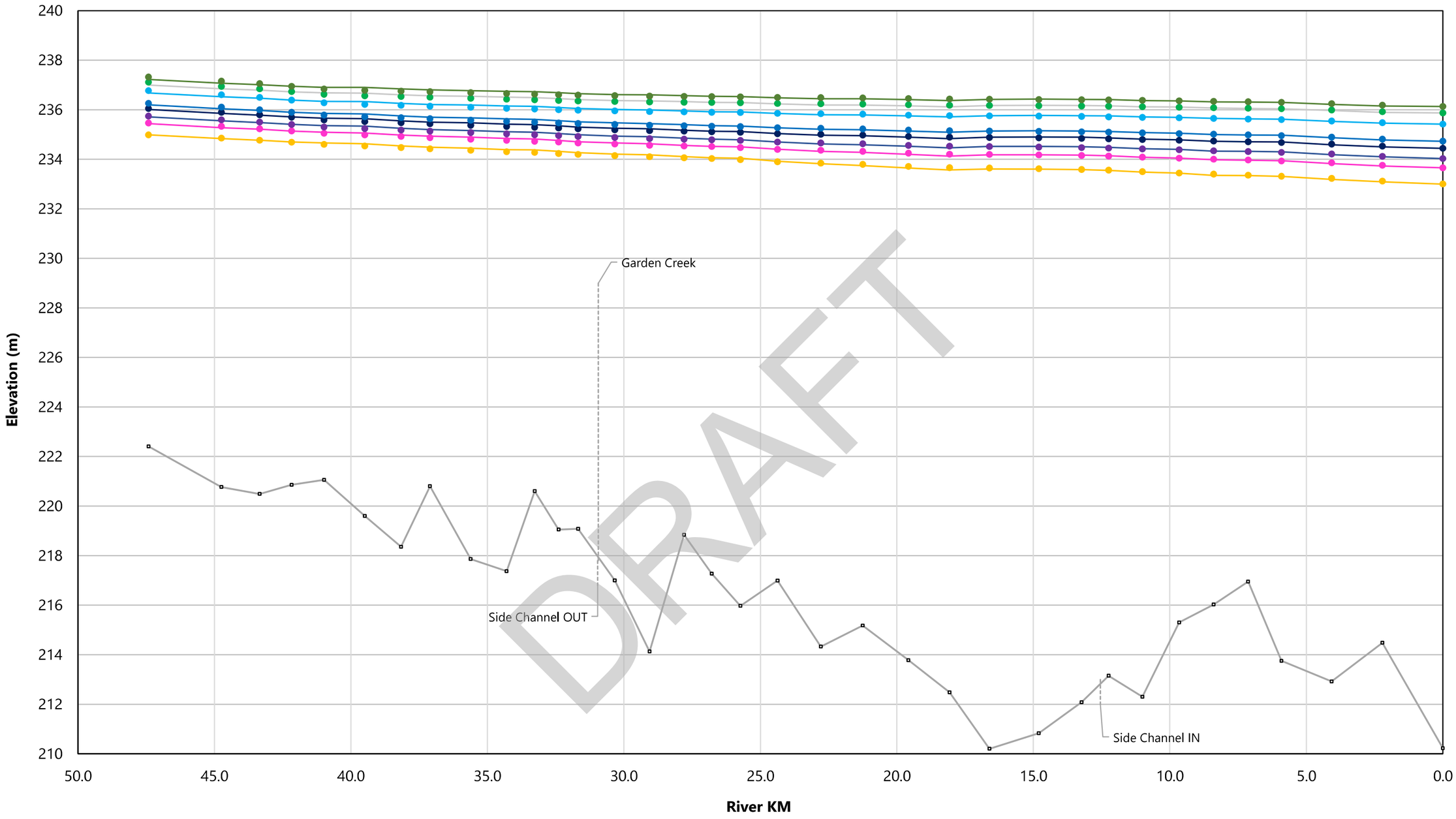
Notes: a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
b) Breakup level distributions are adjusted vertically to align the median to zero. Grey lines represent the family of breakup level distributions computed at all Peace River model sections.
c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

GARDEN RIVER FLOOD STUDY

MONTE CARLO RESULTS
FV $Q_{LOG\ KDE}$ | $PP_{ICE\ TYPES}$

Job: 1009251	Date: May-2026	FIGURE 26

Classification: Public



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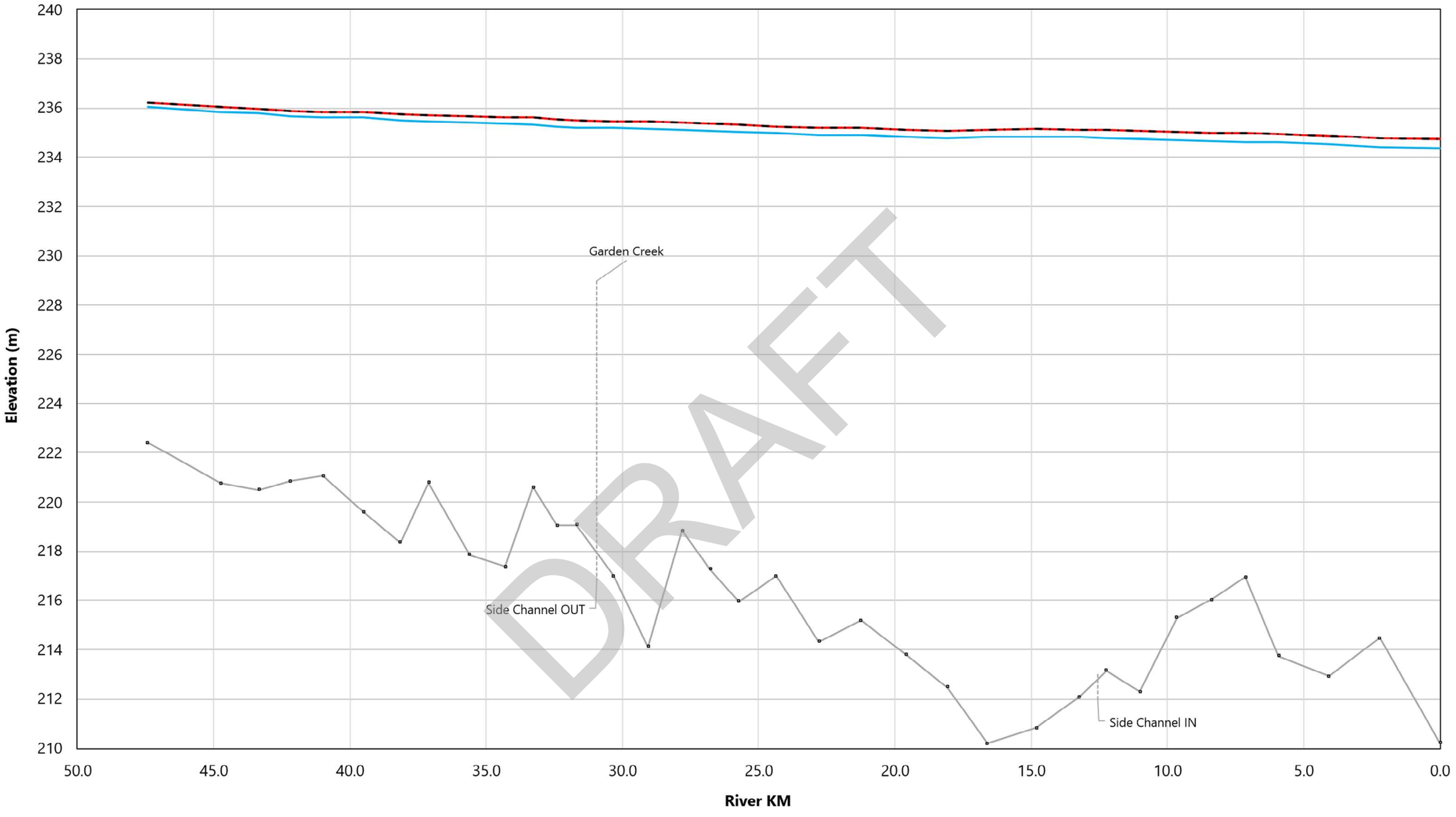
Series4 | 1:20 Ice Jam Flood | 1:35 Ice Jam Flood | 1:50 Ice Jam Flood | 1:75 Ice Jam Flood | 1:100 Ice Jam Flood | 1:200 Ice Jam Flood | 1:350 Ice Jam Flood | 1:500 Ice Jam Flood | 1:20 Monte Carlo Estimate | 1:35 | 1:50 Monte Carlo Estimate | 1:75 Monte Carlo Estimate | 1:100 Monte Carlo Estimate | 1:200 Monte Carlo Estimate | 1:350 Monte Carlo Estimate | 1:500 Monte Carlo Estimate

GARDEN RIVER FLOOD STUDY

PEACE RIVER ICE JAM FLOOD FREQUENCY PROFILES WITH MONTE CARLO ESTIMATES

Job: 1009251	Date: May-2026	FIGURE 27

Classification: Public



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Surveyed Bed

1:100 Open Water Flood

1:100 Ice Jam Flood

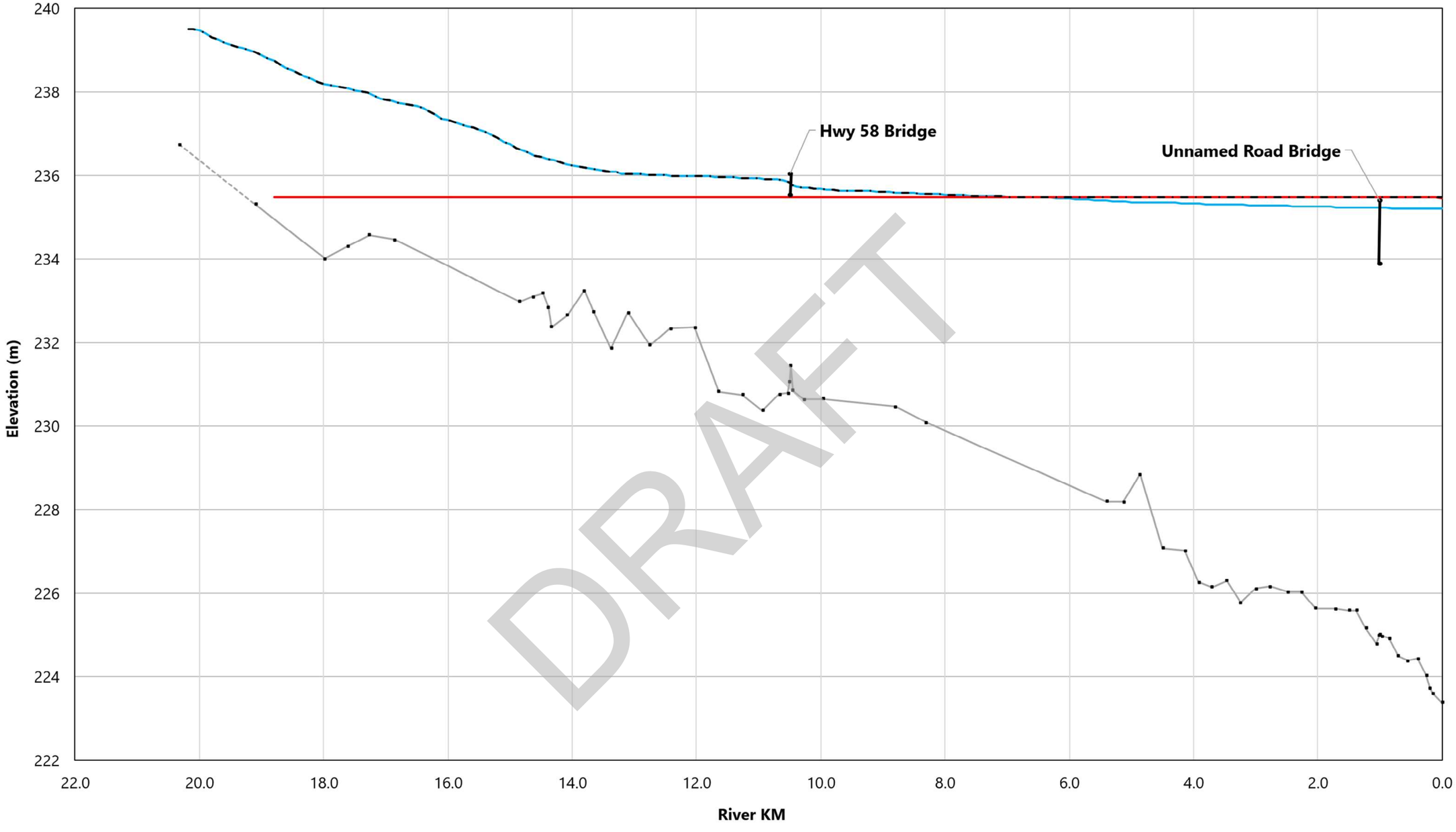
Governing Design Flood

GARDEN RIVER FLOOD STUDY

GOVERNING DESIGN FLOOD PROFILE PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 28

Classification: Public



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Surveyed Bed

Assumed Bed (Extrapolated)

1:100 Open Water Flood

Bridges

high chord

low chord

1:100 Ice Jam Flood

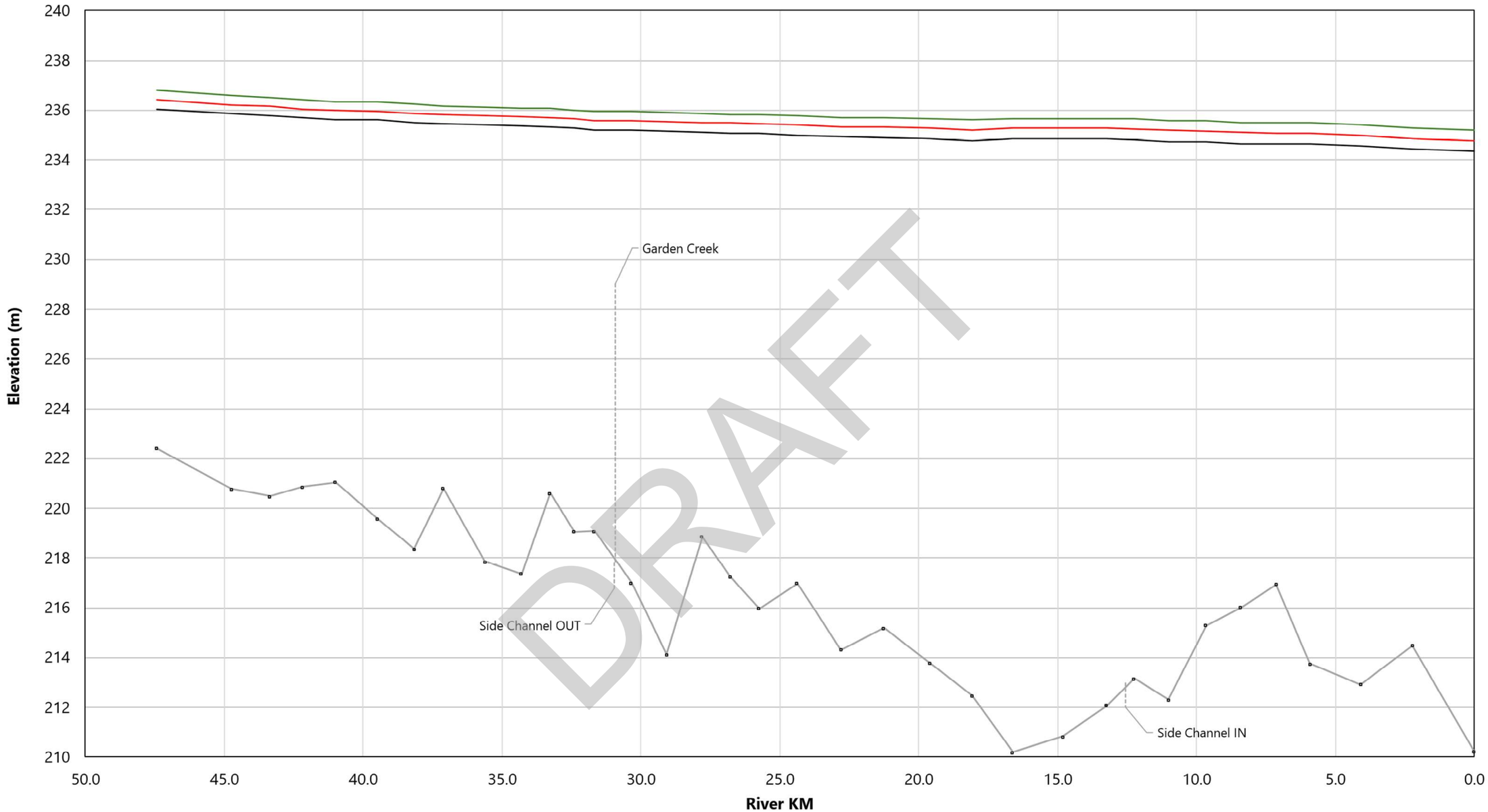
Governing Design Flood

GARDEN RIVER FLOOD STUDY

GOVERNING DESIGN FLOOD PROFILE GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 29

Classification: Public



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Surveyed Bed

1:100 Open Water Flood Baseline (Q = 18,200 cms)

1:100 Open Water Flood (Q + 10% for Climate Change)

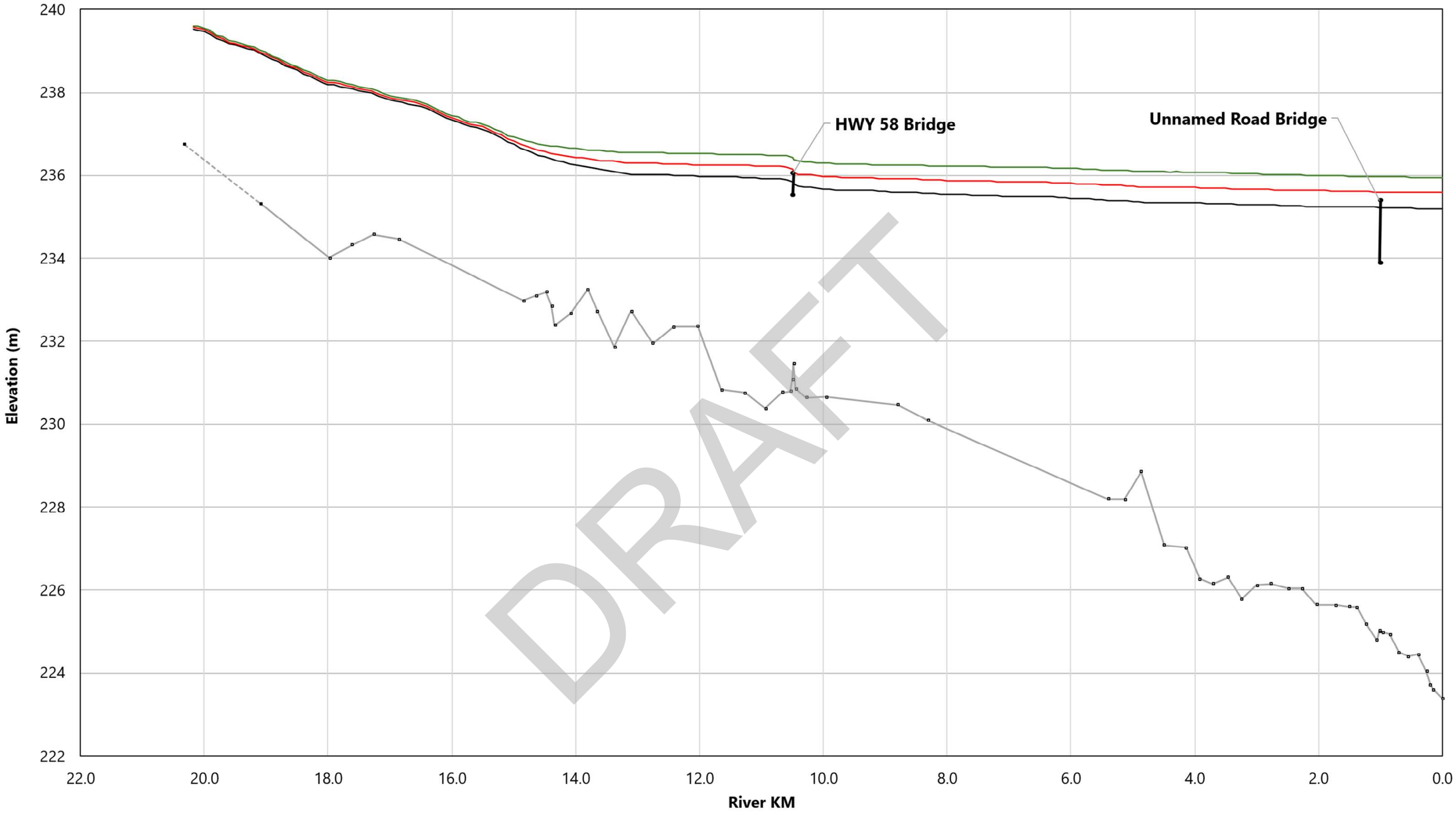
1:100 Open Water Flood (Q + 20% for Climate Change)

GARDEN RIVER FLOOD STUDY

POTENTIAL CLIMATE CHANGE IMPACTS PEACE RIVER

Job: 1009251	Date: May-2026	FIGURE 30

Classification: Public



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Surveyed Bed

Assumed Bed (Extrapolated)

1:100 Open Water Flood Baseline (Q = 105 cms)

1:100 Open Water Flood (Q + 10% for Climate Change)

1:100 Open Water Flood (Q + 20% for Climate Change)

Bridges

high chord

low chord

GARDEN RIVER FLOOD STUDY

POTENTIAL CLIMATE CHANGE IMPACTS GARDEN CREEK

Job: 1009251	Date: May-2026	FIGURE 31

Classification: Public

APPENDIX A

OPEN WATER HYDROLOGY

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Garden River Flood Study

Open Water Hydrology Assessment Report

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DISCLAIMER

This report has been prepared by Northwest Hydraulic Consultants Ltd. for the benefit of Alberta Environment and Protected Areas for specific application to the Garden River Flood Study. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.'s** professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation and were prepared in accordance with generally accepted engineering and geoscience practices.

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The Garden Flood Study was completed by the Government of Alberta under the provincial Flood Hazard Identification Program, the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. The study was co-funded by Parks Canada. NHC would like to thank Government of Alberta and Parks Canada for funding this project.

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- Lance Katan — Hydraulics and Geomorphology Specialist, Project Manager
- Hammad Javid — River Engineer in Training, Backup Project Manager
- Nadia Kovachis Watson — River Hydraulics and Ice Engineer

NHC personnel that participated in this study and their roles are:

- Dan Healy — Project Manager and Technical Lead
- Ken Zhao — Lead Hydrology Specialist
- Makamum Mahmood — Hydrology Specialist
- Kevin Emmelkamp — Project Engineer
- Jerry Yan — GIS Specialist

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APPENDIX SECTIONS

APPENDICES

Appendix A Flow Data Used for Regional Analysis
Appendix B Flood Frequency Analysis for Regional Stations

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ABBREVIATIONS

Acronym / Abbreviation	Definition
AENV	Alberta Environment
EPA	Alberta Environment and Protected Areas
AFETUW	Alberta Flow Estimation Tool for Ungauged Watershed
TEC	Alberta Transportation and Economic Corridors
BC	British Columbia
EPA	Alberta Environment and Protected Areas
G	Gumbel
GEV	Generalized Extreme Value
K-S Test	Kolmogorov-Smirnov Test
LN	Log-Normal
LN3	Three Parameter Log-Normal
LP3	Log-Pearson III
MRDEM	Medium Resolution Digital Elevation Model
N	Normal
NHC	Northwest Hydraulic Consultants
P3	Pearson III
SSAR	Streamflow Synthesis and Reservoir Regulation
STOR	Specific Terms of Reference
TPR	Town of Peace River
USACE	United States Army Corps of Engineers
USGS	United States Geologic Survey
W	Weibull
WSC	Water Survey of Canada

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1 INTRODUCTION

In September 2024, Alberta Environment and Protected Areas (EPA) retained Northwest Hydraulic Consultants Ltd. (NHC) to complete a flood study covering approximately 34 km of the Peace River and 19 km of Garden Creek within Wood Buffalo National Park. The study area spans Mackenzie County, Improvement District No. 24, and the Little Red River Cree Nation community of Garden River. This study is referred to as the Garden River Flood Study. Figure 1.1 shows the study area.

This report presents an open water hydrology assessment for the Peace River and its tributary Garden Creek within the study area. The primary objective of this assessment is to develop flood frequency estimates to support the hydraulic modelling and flood mapping tasks for the Garden River Flood Study.

The specific terms of reference (STOR) for the Garden River Flood Study does not specify sites where flood frequency estimates are required. The Peace River reach within the study area is relatively short. There was a discontinued hydrometric station on the river operated by the Water Survey of Canada (WSC) near the upstream boundary of the study area (WSC Station 07KA002 – Peace River at Fifth Meridian). From this station to the downstream boundary of the study area, the drainage area of the Peace River increases only about 1%. So, the unaccounted flow accretions along this short study reach are insignificant and flood frequency estimates at the discontinued WSC station are appropriate for the entire Peace River study reach. The Garden Creek study reach is located at the downstream end of the creek, and an assessment at the mouth of this creek will be sufficient to characterize flows through the study reach. Accordingly, NHC selected the following two locations as the flood frequency estimate locations for the Garden River Flood Study:

- Peace River at Fifth Meridian (discontinued WSC Station 07KA002)
- Garden Creek at the mouth

These two locations are identified in Figure 1.1.

Flows in the Peace River have been regulated due to BC Hydro's operation at the W.A.C. Bennett Dam and Peace Canyon Dam since 1968, with additional flow regulation at the Site C Dam commissioned in 2024. As the flow regulations could have effects on historical flood peaks in the study area, this study requires flow naturalization to remove effects of the flow regulation, and subsequent flood frequency analysis under the naturalized condition.

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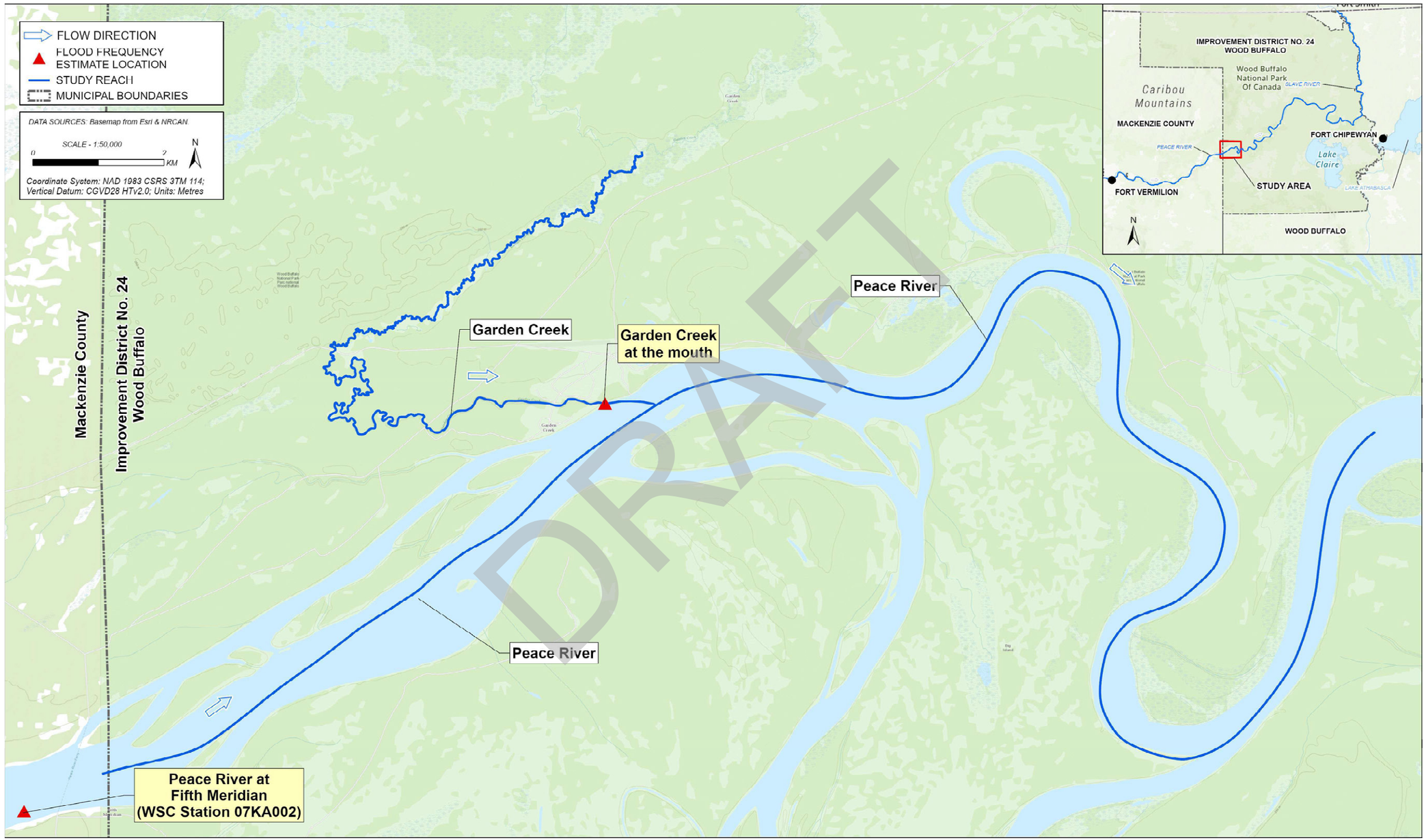


Figure 1.1 Flood study reach

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2 HYDROLOGIC CHARACTERISTICS

2.1 Basin Settings

2.1.1 Peace River

The Peace River basin is depicted in Figure 2.1. Upstream from the WSC Fifth Meridian station (07KA002), the Peace River drainage area is approximately 289,000 km^2 according to WSC (Government of Canada, 2024). This discontinued station provided seasonal flow measurements between 1960 and 1967. The nearest active WSC stations that provide long-term Peace River flow data are Fort Vermilion (07HF001) and Peace Point (07KC001), located about 150 km upstream and 160 km downstream, respectively. According to Government of Canada (2024), the drainage areas of the Peace River for these two stations are 227,000 km^2 and 299,000 km^2, which are 21.5% smaller and 3.5% larger than the drainage area for Station 07KA002, respectively.

The Peace River originates in the Rocky Mountains in northern British Columbia (BC). The headwaters of the river consist of glacial-fed mountain rivers and creeks that feed into Williston Lake, a large reservoir created by the W.A.C. Bennett Dam. Discharges from this dam flows through Dinosaur Lake, the head pond of the Peace Canyon Dam. From the Peace Canyon Dam, the Peace River flows northeast and then southeast into Alberta, passing the recently completed Site C Dam, located approximately 85 km downstream of the Peace Canyon Dam.

In Alberta, the Peace River generally flows eastward toward the town of Peace River (TPR), located about 395 km downstream of the Peace Canyon Dam. Beyond TPR, the river flows north and then northeast for about 435 km to Fort Vermilion, and then another 150 km to the Garden River study area. Ultimately, the Peace River enters the Slave River after passing through the Peace-Athabasca Delta.

Flows in the Peace River are mostly due to runoff from the upper portion of the basin, generated in the mountainous and foothills regions. Regulation of Peace River flows began in 1968 due to BC Hydro's operation at the W.A.C. Bennett and Peace Canyon dams. Primarily due to the significant storage capacity of Williston Lake, the operation imposes relatively significant effects on Peace River flows below the Peace Canyon Dam. Effects of the regulation on flood peak flows at TPR and Fort Vermilion were assessed by NHC (2016, 2020).

2.1.2 Garden Creek

Garden Creek originates in the Caribou Mountains and flows through the Garden River community of the Little Red River Cree Nation. It is a relatively small, ungauged tributary of the Peace River. Figure 2.2 shows the Garden Creek basin boundary, which was delineated based on

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the Medium Resolution Digital Elevation Model (MRDEM) data and Alberta Flow Estimation Tool for Ungauged Watershed (AFETUW). The total area of this basin is approximately 590 km^2.

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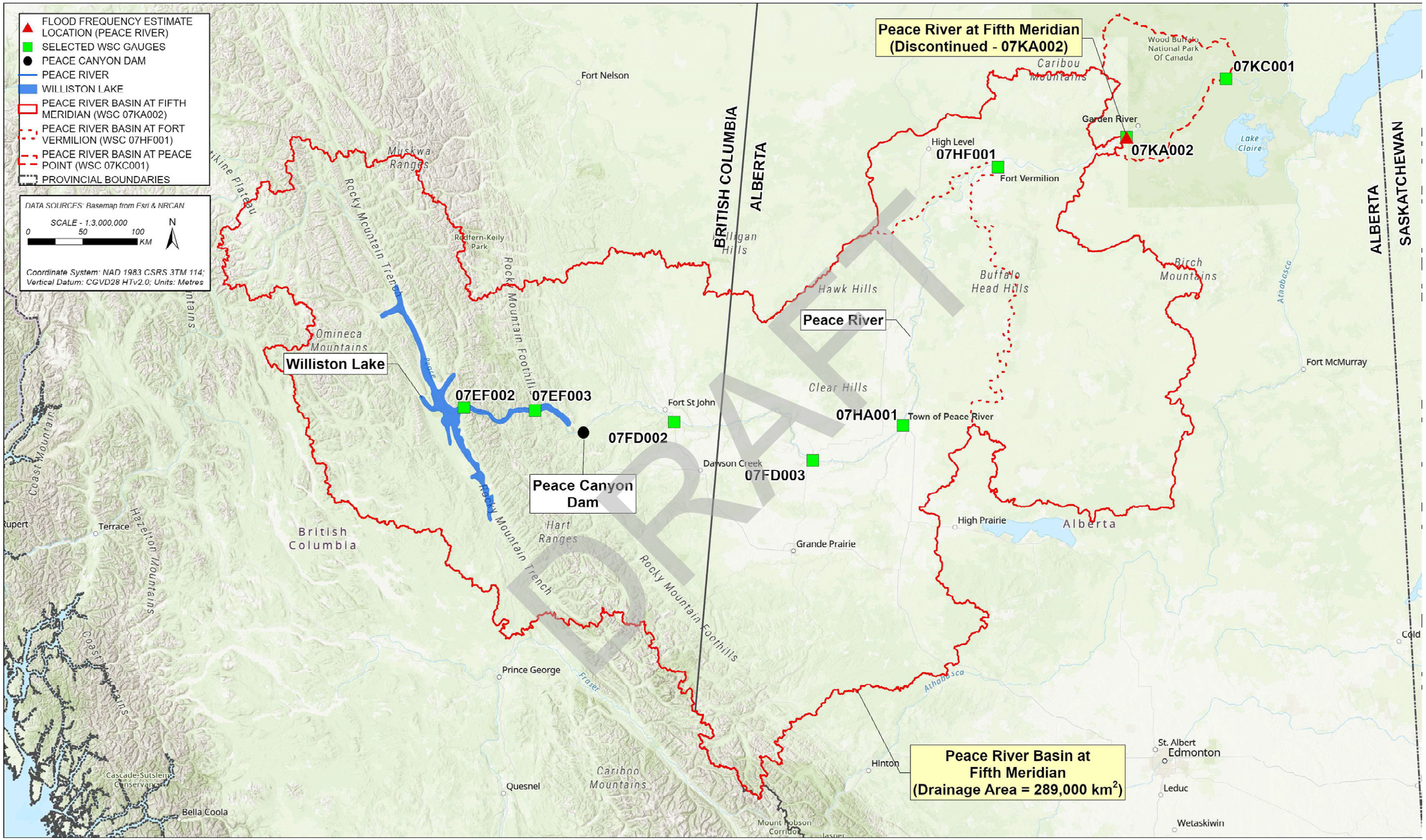


Figure 2.1 Peace River basin

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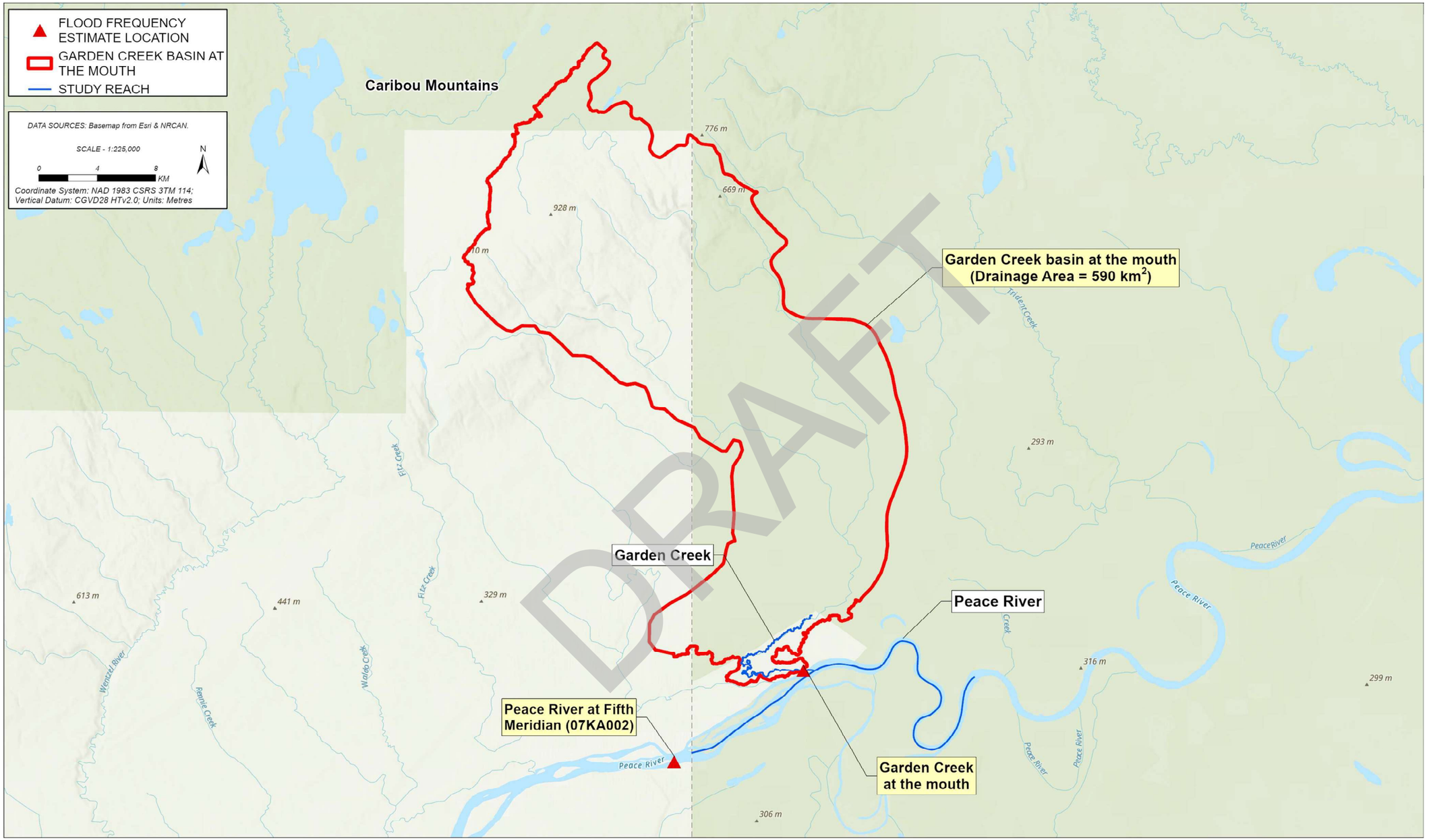


Figure 2.2 Garden Creek basin

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2.2 Flood Characteristics and Historical Floods

The WSC station 07KA002 – Peace River at Fifth Meridian provides only seasonal flow data for a short period between 1960 and 1967. Longer records are available for the gauge stations at Fort Vermilion and Peace Point, and they were used herein to describe the Peace River flood characteristics in the study area.

Available annual maximum daily flows for Peace River at Fort Vermilion (WSC Station 07HF001) and at Peace Point (WSC Station 07KC001) are shown in Figure 2.3. These data are indicative of historical flood magnitude of the Peace River within the study area. Note that flows at Fort Vermilion from 1979 to 1993 were computed from WSC water level data by NHC (2020) because the WSC operated 07HF001 as a water level gauge without flow measurements for this period.

In most years, annual peak flows on the Peace River between Fort Vermilion and Peace Point occur in late May, June and July; but in some years, they occur in April and August. Between 1915 and 2023, the annual peak flows ranged from smaller than 3,000 m^3/s to larger than 12,000 m^3/s. There were nine years when the annual maximum daily flows at Fort Vermilion exceeded 10,000 m^3/s. During these events, the measured flood peaks were higher at Fort Vermilion than at Peace Point, when data are available at both stations. However, in other years when flood peaks were lower, they varied, being either higher or lower at Fort Vermilion compared to Peace Point. This suggests that, during large flood events, the attenuation of peak flows from Fort Vermilion to Peace Point due to floodplain storage effects is generally significant and could not be offset by tributary inflows.

The nine significant open water flood events with maximum daily flows greater than 10,000 m^3/s are listed in Table 2.1 in descending order of magnitude. The June 1990, July 2011 and June 1964 events are the three largest events, and the more recent July 2020 event is the fourth largest event between 1915 and 2023.

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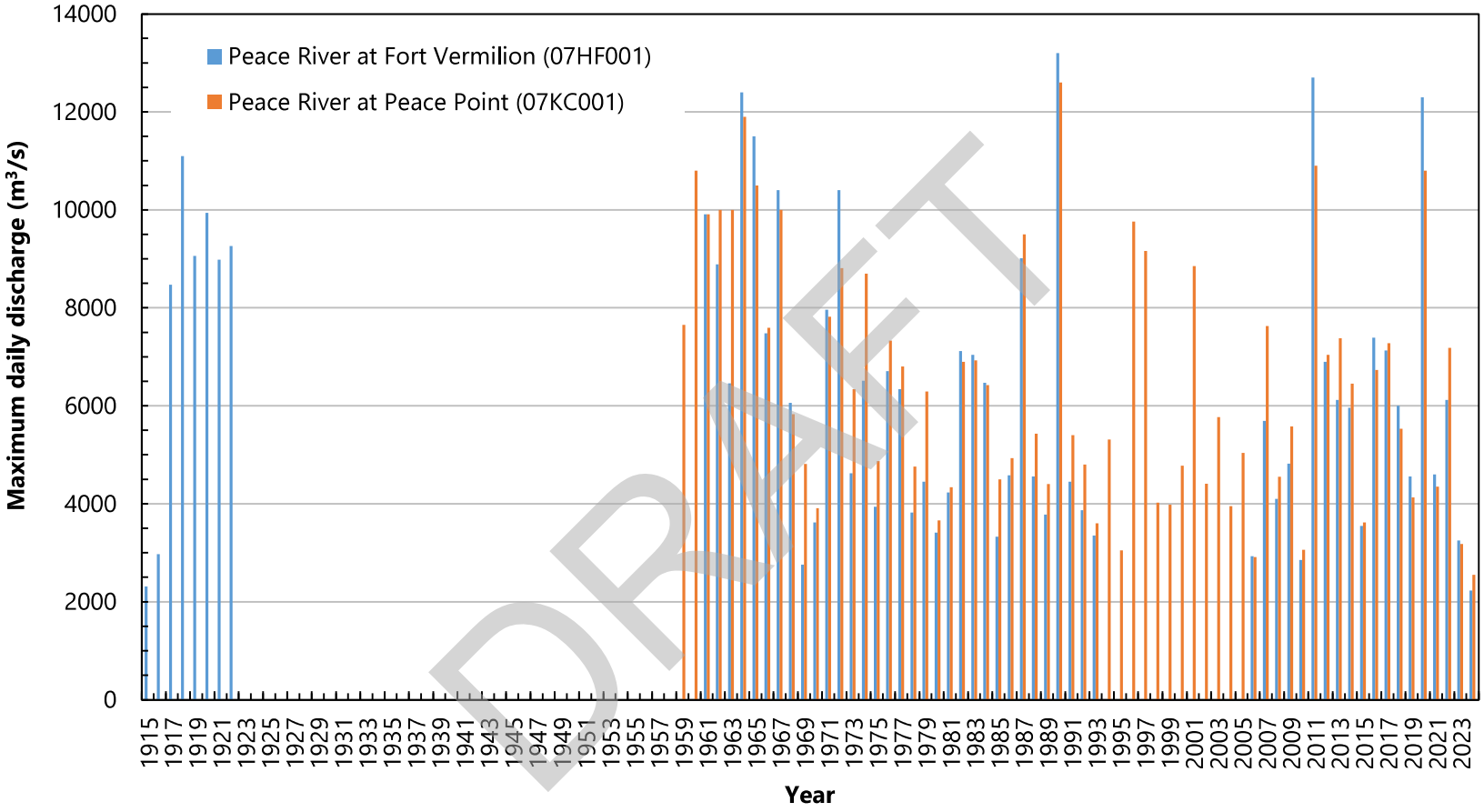
Table 2.1 Summary of significant annual peak flow events on the Peace River between Fort Vermilion and Peace Point

Rank	Year	Fort Vermilion (07HF001)		Peace Point (07KC001)	
		Date	Daily Discharge (m^3/s)	Date	Daily Discharge (m^3/s)
1	1990	06-16[1]	13,200[2]	06-17	12,600
2	2011	07-13	12,700	07-15	10,900
3	1964[3]	06-16	12,400	06-19	11,900
4	2020	07-06	12,300	07-08	10,800
5	1960[3]			6-28	10,800
6	1965[3]	07-13	11,500	07-15	10,500
7	1918[3]	6-22	11,100		
8	1972	6-16	10,400	6-16	8,810
9	1967[3]	6-6	10,400	6-6	10,000

Notes:
1. The date of the maximum daily discharge for 1990 was based on the date in which the maximum water level was recorded by WSC.
2. The maximum discharge for 1990 was estimated from the maximum recorded water level. (NHC 2021).
3. Pre-regulation events.

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Notes:

1. Discharges for Peace River at Fort Vermilion (07HF001) from 1979 to 1993 were derived from gauged water level data by NHC (2020).

Figure 2.3 Annual maximum daily discharges for Peace River at Fort Vermilion and Peace Point

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3 HYDROMETRIC DATA COLLECTION

Through the previous Peace River and Fort Vermilion flood studies, NHC (2016, 2020) developed naturalized daily flow timeseries for the Peace River at TPR and at Fort Vermilion for the 1968 to 2018 period. These data series were extended to 2023 and used in this study for Peace River flow naturalization below Fort Vermilion. To extend the flow naturalization analysis for the Peace River above Fort Vermilion, NHC obtained streamflow and water level data from the WSC for the hydrometric stations listed in Table 3.1.

Table 3.1 WSC stations used to extend previous Peace River flow naturalization for the 2019-2023 period

Type	WSC Station No.	Station Name	Drainage Area (km^2)[1]
Williston Lake water level gauge stations	07EF002	Williston Lake at Lost Cabin Creek	72,100
	07EF003	Williston Lake near Schooler Creek	72,100
Peace River flow gauge stations	07FD002	Peace River near Taylor	101,000
	07FD003	Peace River at Dunvegan Bridge	135,000
	07HA001	Peace River at Peace River	194,000
Tributary flow gauge stations	07FA001/ 07FA006	Halfway River near Farrel Creek[2]	9,290
	07FB001	Pine River at East Pine	12,100
	07FB008	Moberly River near Fort St. John	1,520
	07FC001	Beaton River near Fort St. John	15,500
	07FD001	Kiskatinaw River near Farmington	3,610
	07FD006	Saddle River near Woking	536
	07FD007	Pouce Coupe River below Henderson Creek	2,880
	07FD009	Clear River near Bear Canyon	2,870
	07GJ001	Smoky River at Watino	50,000
	07HA003	Heart River near Nampa	1,950
	07HA005	Whitemud River near Dixonville	2,010
	07HC001	Notikewin River at Manning	4680
	07HC002	Buchanan Creek near Manning	230

Notes:
1. Drainage area is based on the National Hydrometric Network Basin Polygon (Government of Canada, 2024)
2. The daily record for WSC Station 07FA006 – Halfway River near Farrel Creek (Lower Station) was extended using available data from the adjacent discontinued WSC Station 07FA001 – Halfway River near Farrel Creek.

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To complete flow naturalization for the Peace River below Fort Vermilion, NHC obtained available hydrometric data for the WSC stations listed in Table 3.2. The table also includes regional stations considered for the regional analysis for Garden Creek.

Table 3.2 WSC stations used for hydrology assessment

Type	WSC Station No.	Station Name	Drainage Area (km^2)[1]	Period of Data Collected
Peace River flow stations	07HF001	Peace River at Fort Vermilion[2]	227,000	1915-1922, 1961-1978, 1979-1993, 2006-2023, 2024[3]
	07KA002	Peace River at Fifth Meridian	289,000	1960-1964, 1966-1967
	07KC001	Peace River at Peace Point (Alberta)	299,000	1959-2023, 2024[3]
Tributary flow stations	07JD001/ 07JD002	Wabasca River above Peace River / Wabasca River at Highway No. 88[4]	36,400	1963-1970 / 1970-2023, 2024[3]
	07JF002	Boyer River near Fort Vermilion	6,640	1962-2023, 2024[3]
Regional flow stations	07HF002	Keg River at Highway No. 35	664	1971-2023, 2024[3]
	07JC001	Lafond Creek near Red Earth Creek	487	1975-2023, 2024[3]
	07JD003	Jackpine Creek at Highway No. 88	600	1971-2023, 2024[3]
	07JD004	Teepee Creek near La Crete	139	1981-2023, 2024[3]
	07JF003	Ponton River above Boyer River	2,450	1962-2023, 2024[3]
	07JF004 / 07JF005	Boyer River near Paddle Prairie / Boyer River at Paddle Prairie[5]	167	1979-2007 / 2008-2023, 2024[3]

Notes:
1. The reported gross drainage area is based on National Hydrometric Network Basin Polygon (Government of Canada, 2024).
2. Flow data collected include available gauge data and natural and naturalized flow estimates from NHC (2020).
3. Preliminary data obtained from WSC.
4. The daily record for WSC Station 07JD002 – Wabasca River at Highway No. 88 was extended using available data from adjacent discontinued WSC Station 07JD001 – Wabasca River above Peace River.
5. The flood peak record for WSC Station 07JF005 – Boyer River at Paddle Prairie was extended using available data from the adjacent discontinued WSC Station 07JF004 – Boyer River near paddle Prairie.

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4 FLOW NATURALIZATION

4.1 Flow Naturalization Method

Flow naturalization is a process by which anthropogenic effects, such as regulation due to storage or diversion of flow, are removed to re-create the natural flow that would have occurred in the absence of these interventions. The objective of the flow naturalization process in this study is to estimate natural daily discharges of annual open-water peak events on the Peace River at Garden River, by removing effects imposed by the W.A.C. Bennett Dam from 1968 to

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2023. The Site C Dam was not considered in this study because it did not affect Peace River flows prior to 2024.

The flow naturalization process for this study follows the project depletion approach used in various studies in Alberta, including the previous Peace River and Fort Vermilion flood studies. This approach involves a water balance analysis to naturalize flows at a regulation structure (which is the W.A.C. Bennett Dam in this study) and downstream flow routing through the following steps:

1. Gauged regulated flows at a station on the mainstem river are routed to a downstream gauge station together with gauged or estimated natural tributary inflows.
2. The routed and gauged flows at the downstream station are compared, and differences are taken as gauge corrections which account for ungauged tributary inflows for this sub-reach plus errors from the routing model.
3. Naturalized flows at the upstream station are routed to the downstream station together with the gauged tributary inflows.
4. The gauge corrections are applied to the routed naturalized flows at the downstream station to obtain naturalized flow estimates for this station.
5. These steps are repeated for downstream sub-reaches to the study site.

4.2 Natural and Naturalized Flows at Peace River and Fort Vermilion

Flow naturalization to remove the effects of BC Hydro's operation at the W.A.C. Bennet and Peace Canyon dams was completed as part of the Peace River and Fort Vermilion flood studies by NHC (2016, 2020). Through these studies, NHC developed natural flows (representing the streamflow before regulation) and naturalized flows for the TPR (07HA001) and Fort Vermilion (07HF001) gauge stations between 1915 and 2018. The analysis was extended for this study using 2019-2023 flow and water level data for the Peace River and Williston Lake obtained from the WSC. The extended naturalized Peace River flow data series were used as inputs for the flow naturalization of this study. Note that, while Peace River flow data were also available for 2024, the flow naturalization of this study did not include this year because the flows were affected by the Site C reservoir filling.

The development of the naturalized flows for the TPR (07HA001) and Fort Vermilion (07HF001) follows the process described in Section 4.1 and is summarized as follows:

1. Daily inflows to Williston Lake were estimated through a water balance analysis based on the lake water level and outflow data from the WSC and BC Hydro.
2. A channel routing model was created for the Peace River from Peace Cayon Dam to TPR then to Fort Vermilion. The model was based on the Streamflow Synthesis and Reservoir Regulation (SSARR) method (described in the next section). The model consisted of multiple

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Peace River sub-reaches defined in accordance with WSC's long-term flow gauge stations (key stations) on the Peace River between Peace Cayon Dam and Fort Vermilion.

3. Outflows from Peace Canyon Dam (regulated flows) were routed with gauged and estimated tributary flows being added to each sub-reach develop gauge corrections for each of the key Peace River stations.
4. The estimated inflows to Williston Lake (naturalized flows) were routed from Peace Canyon Dam down the Peace River to TPR and Fort Vermilion, with gauged and estimated tributary flows being added to each sub-reach and gauge corrections being applied to the key Peace River stations.

It involved estimating natural daily inflows to Williston Lake via a water balance analysis and then routing the estimated reservoir inflows along with downstream tributary inflows through the Peace River with no regulations (no dams), using a channel routing model. Gauge corrections were developed

Additional details including data used in the process are provided in the previous study reports (NHC, 2016 and 2020).

4.3 Routing Model Configuration

Flow naturalization for this study is to estimate naturalized flood peak discharges for the Peace River at Fifth Meridian and Peace Point by routing the naturalized flows from Fort Vermilion to Peace Point, together with tributary inflows and gauge corrections. The analysis generally follows the same approach described above. The Peace River channel routing analysis was performed at a daily time step using HEC-ResSim of the U.S. Army Corps of Engineers (USACE). Figure 4.1 depicts the structure of the routing model.

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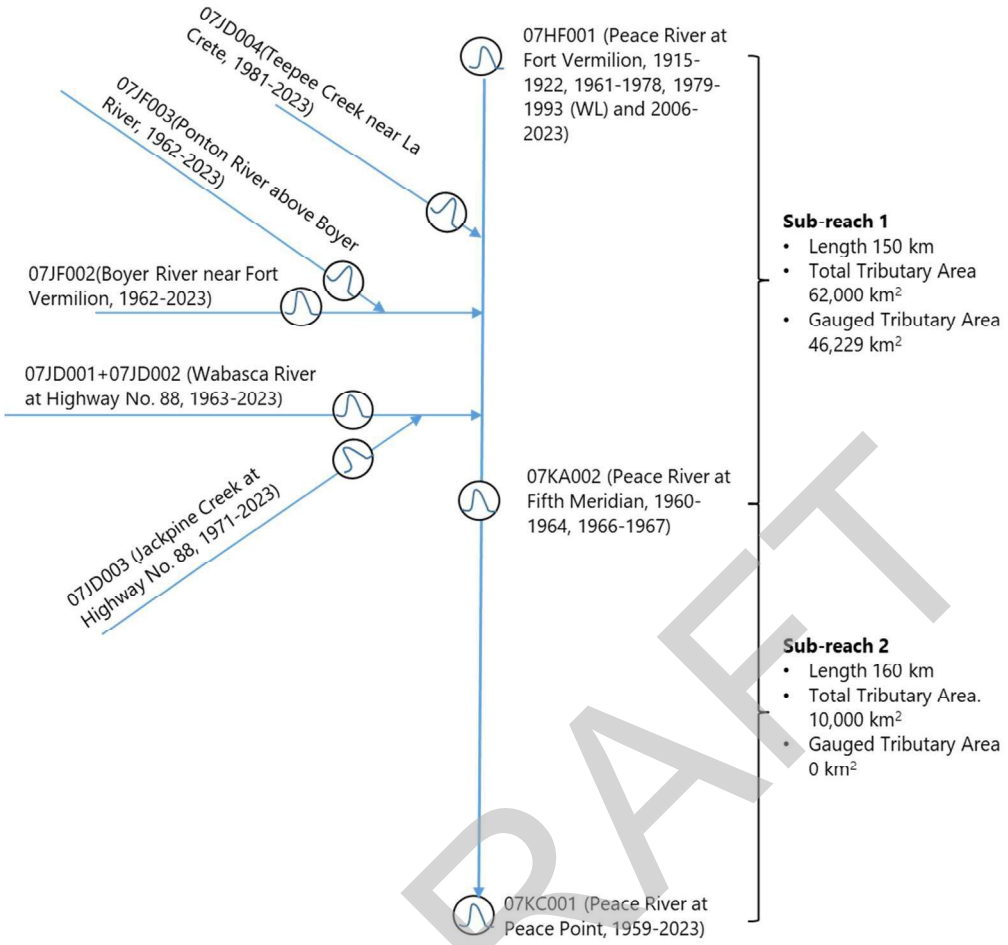


Figure 4.1 Flow routing model schematic

HEC-ResSim currently supports eight hydrologic channel routing methods. In this and previous studies, the SSARR method was used. This method was developed by USACE and has been widely used across Alberta by EPA for water supply studies, flood forecasting and other projects. It simulates channel routing based on reach-specific discharge-travel time relationships that are provided as input. The relationship can be defined by a table of discharge vs. travel time, or by the following formula:

$$T_s = \frac{KTS}{Q^n} \qquad \textbf{(Equation 1)}$$

where T_s is travel time (or time of storage) in hours; Q is discharge in m^3/s; KTS and n are coefficients. The method also requires specifying the number of routing phases (N). The routing parameters (KTS, n and N) or the discharge vs. travel time table are usually determined by calibration against observed hydrographs or from average flow velocity estimates based on channel geometry data.

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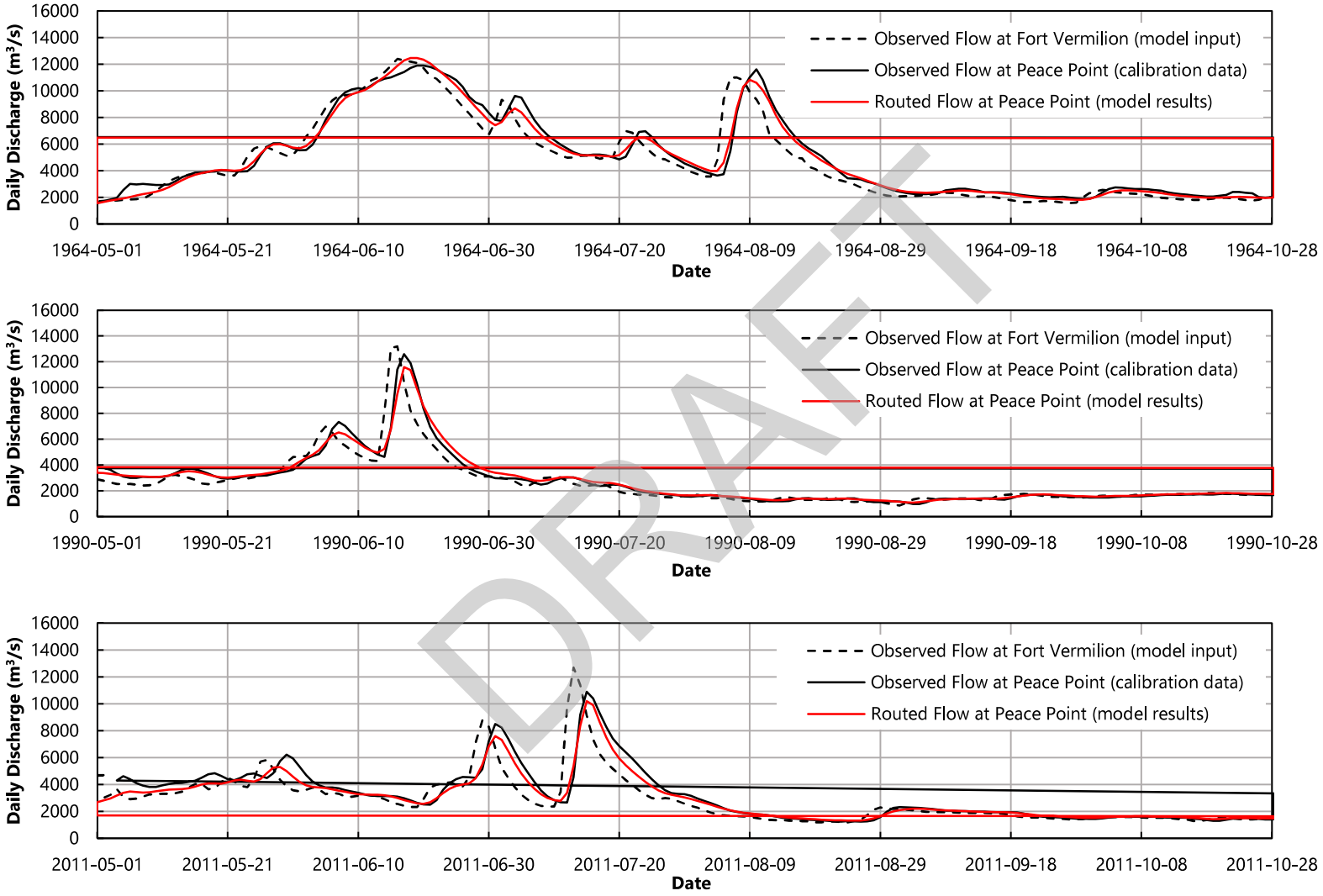
The values of the routing parameters for the Peace River above Fort Vermilion were from NHC (2020). Initial estimates of the parameters for the sub-reaches between Fort Vermilion and Peace Point were made by prorating travel times between TPR and Fort Vermilion by the ratio of the sub-reach lengths. They were then adjusted through calibration against the WSC gauge data. The calibration focused on producing hydrographs at Peace Point with the shape and timing similar to the observed flows, without applying any gauge corrections. Figure 4.2 shows the calibration results for the three record-high flood events as examples. The adopted routing parameters are summarized in Table 4.1.

Table 4.1 Adopted SSARR routing parameters for Peace River from Fort Vermilion to Peace Point

Sub-reach	KTS	n	Number of Routing Phases
Fort Vermilion (07HF001) to Fifth Meridian (07KA002)	647	0.38	1
Fifth Meridian (07KA002) to Peace Point (07KC001)	703	0.38	1

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Figure 4.2 Examples of routing model calibration results

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4.4 Estimation of Naturalized and Natural Flows below Fort Vermilion

4.4.1 Flow Estimation for 1959 to 2023 Period

The natural and naturalized flow routing analysis was first performed from Fort Vermilion to Peace Point for the 1959-2023 period. In this period, the Peace Point station (07KC001) provides natural (pre-regulated) flow data from 1959 to 1967 and regulated flow data from 1968 to 2023. These data were used to determine gauge corrections for Fifth Meridian and Peace Point. The natural and naturalized flows at these two locations were then computed by routing the natural and naturalized flows from Fort Vermilion.

The Fifth Meridian station (07KA002) provided only seasonal flow measurements from 1960 to 1967, with data for 1965 missing. This operating period might be too short for the WSC to establish a reliable stage-discharge rating relationship for this gauge station. The reported flood peaks are noticeably lower than the corresponding peaks at Fort Vermilion and Peace Point. This discrepancy suggests that the data at Fifth Meridian are erroneous, as the flood magnitude at Fifth Meridian is expected to be between those of the other two stations. As such, gauge corrections cannot be determined from the data for the Fifth Meridian station. Alternatively, gauge corrections were estimated from an interactive approach described in the following, based on the available gauge data for the Peace Point station (1959-2023).

Gauged flows were routed from Fort Vermilion to Peace Point. For the 1994-2005 period when flows at Fort Vermilion were not gauged by the WSC, the estimates from NHC (2020) were used. Available gauged flow data from the Peace Point station were used to determine initial gauge correction estimates. Assuming that the gauge corrections were primarily due to tributary inflows between Fort Vermilion and Peace Point, we divided the initial correction estimates into two parts based on the ratio of the ungauged tributary areas within the Fort Vermilion to Fifth Meridian sub-reach and the Fifth Meridian to Peace Point sub-reach. The divided corrections were then applied to the Fifth Meridian and Peace Point stations, respectively, considering a one-day flood wave travel time between these two stations. The one-day travel time assumed herein is equivalent to the travel time determined by Equation (1) for the historical average Peace River flood peaks (about 7,000 m^3/s). Note that, based on Equation (1) and the routing parameters in Table 4.1, the flood trave times from Fort Vermilion to Fifth Meridian and from Fifth Meridian to Peace Point are similar, ranging from about 17 hours for a flow of 15,000 m^3/s to about 28 hours for 5,000 m^3/s.

The routing from Fort Vermilion to Peace Point was repeated with the gauge corrections for both Fifth Meridian and Peace Point. The routed flows at Peace Point were then compared with the gauge data again to determine if further corrections were required. The additional corrections were then divided and applied to the Fifth Meridian and Peace Point stations. This process was repeated until the routed flows equalled the gauged flows at Peace Point.

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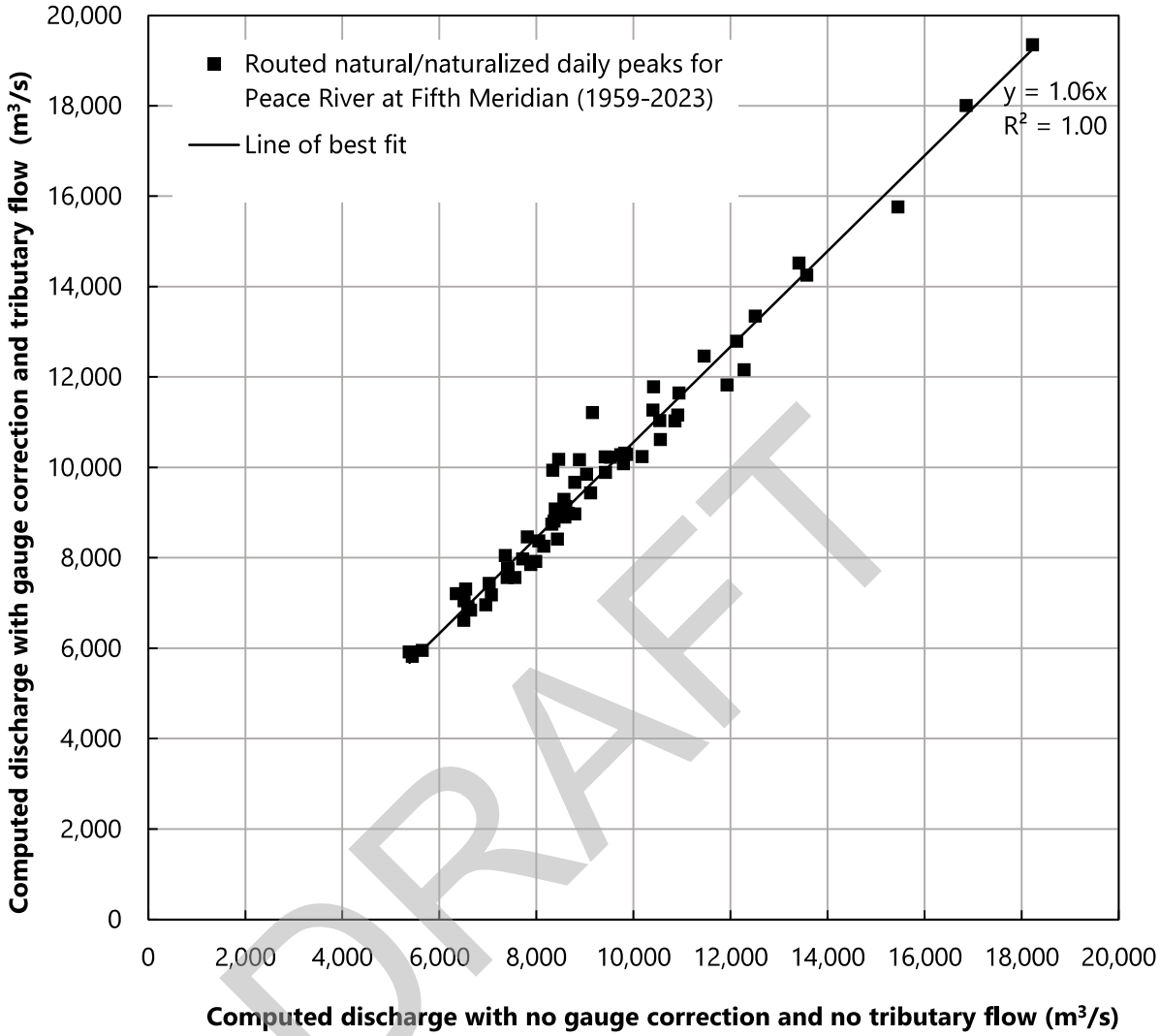
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After the gauge corrections were determined for the Fifth Meridian and Peace Point stations, the natural (1959-1967) and naturalized (1968-2023) flows for Fort Vermilion were routed to Peace Point.

The natural and naturalized flow routing analysis for this period was also performed without the gauge corrections and gauged tributary inflows. The resulting annual maximum values for the Fifth Meridian and Peace Point stations from this scenario are compared with the results accounting for the gauge corrections and tributary inflows to assess effects of the gauge corrections applied in the flow naturalization process. As shown in Figure 4.3 and Figure 4.4, the gauge corrections and gauged tributary inflows represents about 6% and 8% of the naturalized maximum daily flows at Fifth Meridian and at Peace Point, respectively.

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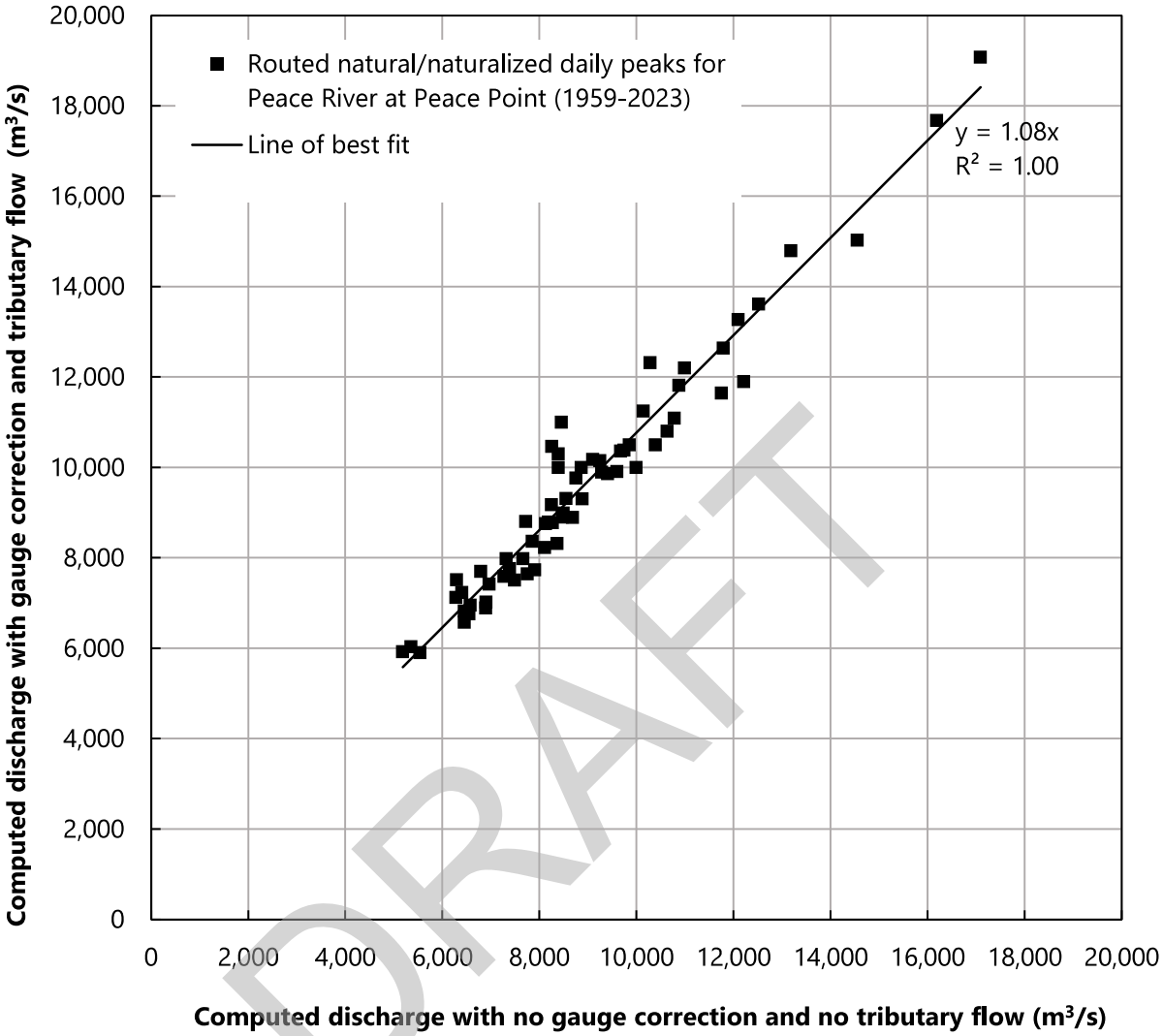
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Figure 4.3 Effects of gauge corrections and gauged tributary inflows on natural and naturalized flood peaks at Fifth Meridian

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Figure 4.4 Effects of gauge corrections and gauged tributary inflows on naturalized flood peaks at Peace Point

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4.4.2 Flow Estimation Prior to 1959

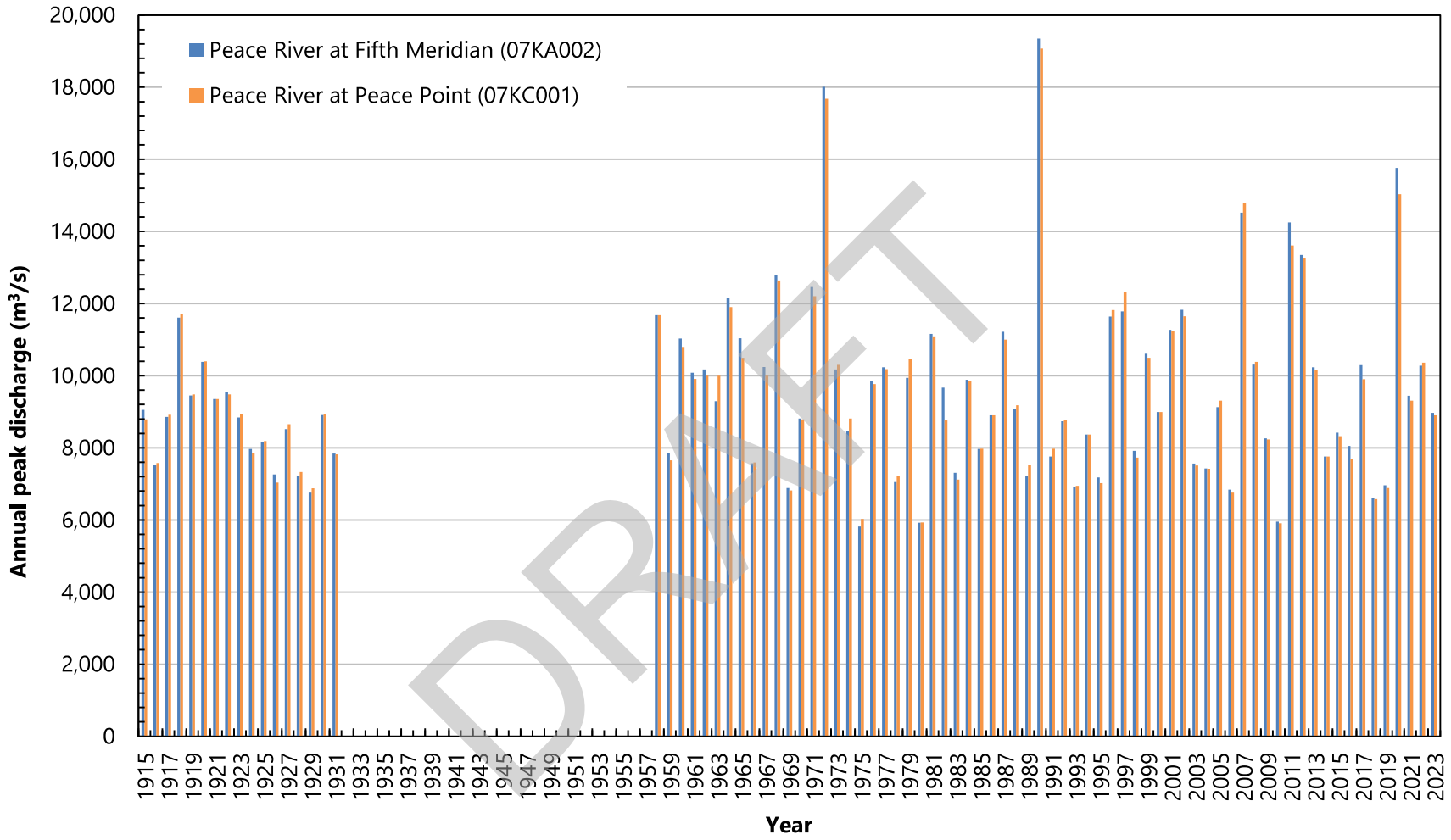
Gauged and estimated natural Peace River flows at Fort Vermilion are available for the 1915-1931 period and 1958. However, gauge data are not available for Peace Point or tributary inflows for these years. The natural flows were routed from Fort Vermilion to Peace Point without gauge corrections. The resulting annual maximum daily discharges from the routed flow series for Fifth Meridian and Peace Point were increased by 6% and 8%, respectively, to account for gauge correction based on the relationships shown in Figure 4.3 and Figure 4.4. The adjusted values were taken as the annual maximum discharge estimates for Fifth Meridian and Peace Point for the 1915-1931 period and 1958. This follows the same approach as employed for the Fort Vermilion flood study (NHC, 2020).

4.4.3 Flow Naturalization Results

From the flow naturalization analysis described above, we obtained natural and naturalized annual maximum daily flow estimates for Fifth Meridian and Peace Point for the periods from 1915 to 1931 and from 1958 to 2023. These estimates are illustrated in Figure 4.5.

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Figure 4.5 Estimated natural and naturalized annual maximum daily flows for Peace River at Fifth Meridian and at Peace Point

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NHC selected Peace River at Fifth Meridian (07KA002) as a flood frequency estimate site for this study as indicated in Section 1. Table 4.2 provides a summary of the natural/naturalized annual maximum daily (Q_d) and instantaneous (Q_p) flows for this site. The instantaneous values were estimated using the relationship (Q_p=1.02Q_d) illustrated Figure 4.6, which is based on the available pre-regulation flow data for all WSC gauge stations on the Peace River from Taylor to Peace Point.

Table 4.2 Natural and naturalized annual peak flows for Peace River at Fifth Meridian

Year	Peak Instantaneous Discharge[1] (m^3/s)	Peak Daily Discharge (m^3/s)	Date
1915	9230	9050	Jul-17
1916	7680	7530	Jul-11
1917	9040	8860	Jun-10
1918	11840	11610	Jun-23
1919	9640	9450	Jun-28
1920	10590	10380	Jun-22
1921	9540	9350	Jun-13
1922	9730	9540	Jun-9
1923	9020	8840	Jun-19
1924	8130	7970	May-22
1925	8320	8160	May-24
1926	7410	7260	Jun-22
1927	8690	8520	Jun-17
1928	7370	7230	Jun-3
1929	6900	6760	Jun-11
1930	9090	8910	Jun-23
1931	8000	7840	Jun-23
1958	11910	11680	Jun-3
1959	8010	7850	Jul-2
1960	11250	11030	Jun-27
1961	10280	10080	Jun-1
1962	10370	10170	Jul-2
1963	9480	9290	May-31
1964	12400	12160	Jun-18
1965	11260	11040	Jul-14
1966	7720	7570	Jun-16
1967	10440	10240	Jun-7
1968	13050	12790	Jun-17
1969	7030	6890	Jun-9
1970	8990	8810	Jun-10

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Year	Peak Instantaneous Discharge[1] (m^3/s)	Peak Daily Discharge (m^3/s)	Date
1971	12710	12460	Jun-21
1972	18370	18010	Jun-16
1973	10370	10170	Jun-21
1974	8640	8470	Apr-30
1975	5940	5820	May-23
1976	10050	9850	Jul-1
1977	10430	10230	Jun-14
1978	7190	7050	Jun-9
1979	10140	9940	Jun-9
1980	6040	5920	Jun-24
1981	11380	11160	Jun-1
1982	9860	9670	Jul-20
1983	7460	7310	Jun-26
1984	10090	9890	Jun-14
1985	8130	7970	Jun-9
1986	9080	8900	Jun-5
1987	11440	11220	Aug-6
1988	9260	9080	Jun-16
1989	7350	7210	May-15
1990	19740	19350	Jun-16
1991	7920	7760	Jun-19
1992	8910	8740	Jun-20
1993	7050	6910	May-22
1994	8540	8370	Jun-19
1995	7320	7180	May-21
1996	11870	11640	Jun-10
1997	12020	11780	Jun-7
1998	8080	7920	Jun-1
1999	10820	10610	Jun-22
2000	9170	8990	Jun-16
2001	11500	11270	Jul-24
2002	12070	11830	Jun-21
2003	7710	7560	Jun-16
2004	7580	7430	Jun-13
2005	9310	9130	May-23
2006	6980	6840	Jun-1
2007	14810	14520	Jun-11
2008	10520	10310	Jun-4

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Year	Peak Instantaneous Discharge[1] (m^3/s)	Peak Daily Discharge (m^3/s)	Date
2009	8430	8260	Jun-17
2010	6070	5950	May-27
2011	14540	14250	Jul-14
2012	13620	13350	Jun-12
2013	10430	10230	Jun-5
2014	7920	7760	May-28
2015	8590	8420	May-31
2016	8210	8050	Jun-21
2017	10500	10290	Jun-15
2018	6740	6610	May-20
2019	7100	6960	Jun-3
2020	16080	15760	Jul-7
2021	9630	9440	Jun-8
2022	10490	10280	Jun-12
2023	9150	8970	May-22

Notes:

1. The instantaneous discharges are based on $Q_p = 1.02Q_d$.

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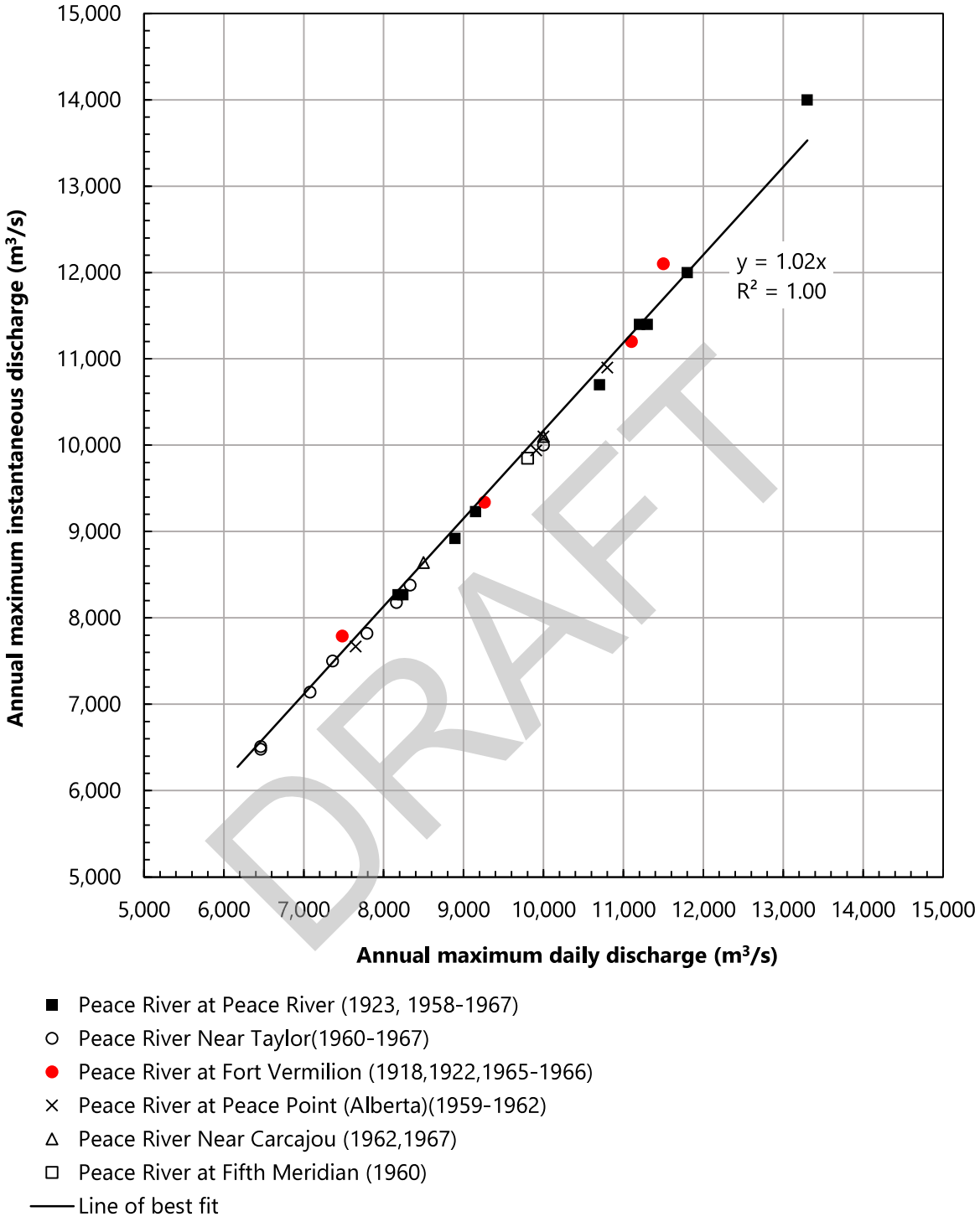


Figure 4.6 Relationships between maximum instantaneous and daily flows for Peace River pre-regulation flows (from NHC, 2016)

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5 FLOOD FREQUENCY ANALYSIS

The objective of this task is 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, for the Peace River and Garden Creek.

5.1 Methodology

The frequency analysis was performed for natural or naturalized annual maximum instantaneous flows using the USACE HEC-SSP (version 2.2) flood frequency program and a spreadsheet model developed by NHC. In accordance with the Flood Hazard Identification Program (FHIP) guidelines (EPA, 2022), Hydrologic and Hydraulic Guidelines for Flood Hazard Area Delineation by AENV (2008), Guidelines on Flood Frequency Analysis by Alberta Transportation (AT, 2001), and Guidelines for Determining Flood Frequency by USGS (2018), various theoretical probability distributions were tested, including the normal (N), log-normal (LN), three parameter log-normal (LN3), Pearson type III (P3), log-Pearson type III (LP3), Gumbel (G), generalized extreme value (GEV), and Weibull distributions. In accordance with AT (2001), the method of moments was used in the calculation of means, variances, and skew coefficients with theoretical limits being considered. The Cunnane plotting position formula (Cunnane, 1978) was used to plot data points for visualization purposes. An analysis following the Guidelines for Determining Flood Frequency – Bulletin 17C (USGS, 2018) was also performed in this study.

The goodness of fit of each of the distributions, as applied to a flood series, was compared through the Kolmogorov–Smirnov test (K-S test). The K-S test can be used to compare a sample with a reference probability distribution. It quantifies a distance between the empirical probability of the sample and the cumulative distribution function of the reference distribution. The maximum distance (referenced to as D-statistic value, D_n) can be used to describe the goodness of fit, where a smaller D_n value would indicate a better fit between the empirical distribution and the theoretical one.

The goodness of fit was also evaluated with a least square method (Kite, 1977) is based on the sum of squared errors (*SSE*) calculated by:

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

where n is the number of recorded events, m is the number of parameters used by a frequency distribution, x_i is the i^{th} recorded peak discharge, and y_i is the discharge computed from the frequency distribution at the probability equal to the empirical probability of discharge x_i.

The *SSE* values of the tested probability distributions were then normalized by the mean peak discharge (Q_{pm}, the average of the annual peak discharges for each station) to provide a

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dimensionless *SSE*. In this approach a lower dimensionless *SSE* would indicate a better fit between the empirical distribution and the theoretical one.

Each of these methods has their own advantages and disadvantages. The D_n value from the K-S test is defined as the maximum discrepancy between the predicted probabilities (for given flood peaks) by the frequency curve and empirical probabilities from the data sample, while the SSE value represents the average deviation of predicted flood peaks from the measured or estimated discharges.

In this study, the applied frequency distributions were ranked first by D_n and *SSE* values separately, and the sums of the rankings were then compared to derive the final combined ranking. Note, however, that using these statistical methods tends not to provide a foolproof assessment of the goodness of fit along the tails of the distributions, which are especially important in defining the return periods of the severe floods. Therefore, the selection of the best representative distribution is based as much on judgement and visual assessment as it is on the statistical ranking result.

5.2 Analysis for Peace River at Fifth Meridian and Peace Point

As discussed in Section 1, NHC selected the discontinued WSC station 07KA002 – Peace River at Fifth Meridian as the flood frequency estimation site representing Peace River flows through the Garden River study area. So, a frequency analysis was performed for this site with the data listed in Table 4.2. A summary of the statistical parameters for the peak instantaneous flow series is provided in Table 5.1.

Table 5.1 Summary of statistical parameters of annual peak instantaneous flow series for Peace River at Fifth Meridian

Parameter	Annual Instantaneous Peak Flow Series (1915 – 1931, 1958 – 2023)
Total years of record	83
Mean (m^3/s)	9,710
Median (m^3/s)	9,230
Standard deviation (m^3/s)	2,530
Coefficient of variation	0.261
Skew coefficient (minimum, maximum, actual)	0.521, 1.34, 1.51

Each of the frequency distributions in the adopted suite were fitted to the data. The goodness of fit of each of the distributions, as applied to a flood series, was compared through the K-S test and least squares method. Rankings of the frequency curves are shown in Table 5.2. The GEV curve produced the lowest D_n and second lowest *SSE* value and is ranked the best in the

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combined ranking. The LP3 curve produced the lowest *SSE* value and slightly higher D_n value, and it is ranked the second best in the combined ranking. These two curves are followed by the frequency curves based on Bulletin 17C and the LN3 distribution. As shown in Figure 5.1, these four frequency curves are very similar, and they all fit the data reasonably well. It is recommended that the LP3 curve be used herein to describe the natural/naturalized flood peaks for the Peace River at Fifth Meridian as it fits the three largest floods (1990, 1972, and 2020) slightly better. This selection is also consistent with the flood frequency curves for the Peace River at TPR and Fort Vermilion adopted by the previous studies (NHC, 2016 and 2020). The adopted LP3 curve for Peace River at Fifth Meridian with the 95% confidence limits is shown in Figure 5.2.

Table 5.2 Goodness-of-fit comparison for probability distributions for natural/naturalized Peace River flood peaks at Fifth Meridian

Distribution	D_n	Normalized *SSE* (Q_{pm} = 9,710 m^3/s)	Ranking		
			D_n	*SSE*	Combined
Normal (N)	0.111	0.087	8	8	8
Log-normal (LN)	0.059	0.056	6	7	7
Three-parameter log-normal (LN3)	0.052	0.030	5	2	4
Pearson III (P3)	0.061	0.035	7	5	6
Log-Pearson III (LP3)	0.051	0.029	4	1	2
Gumbel (G)	0.049	0.037	2	6	5
Generalized extreme value (GEV)	0.045	0.030	1	2	1
Weibull (W)	0.125	0.098	9	9	9
Bulletin 17C	0.049	0.031	2	4	3

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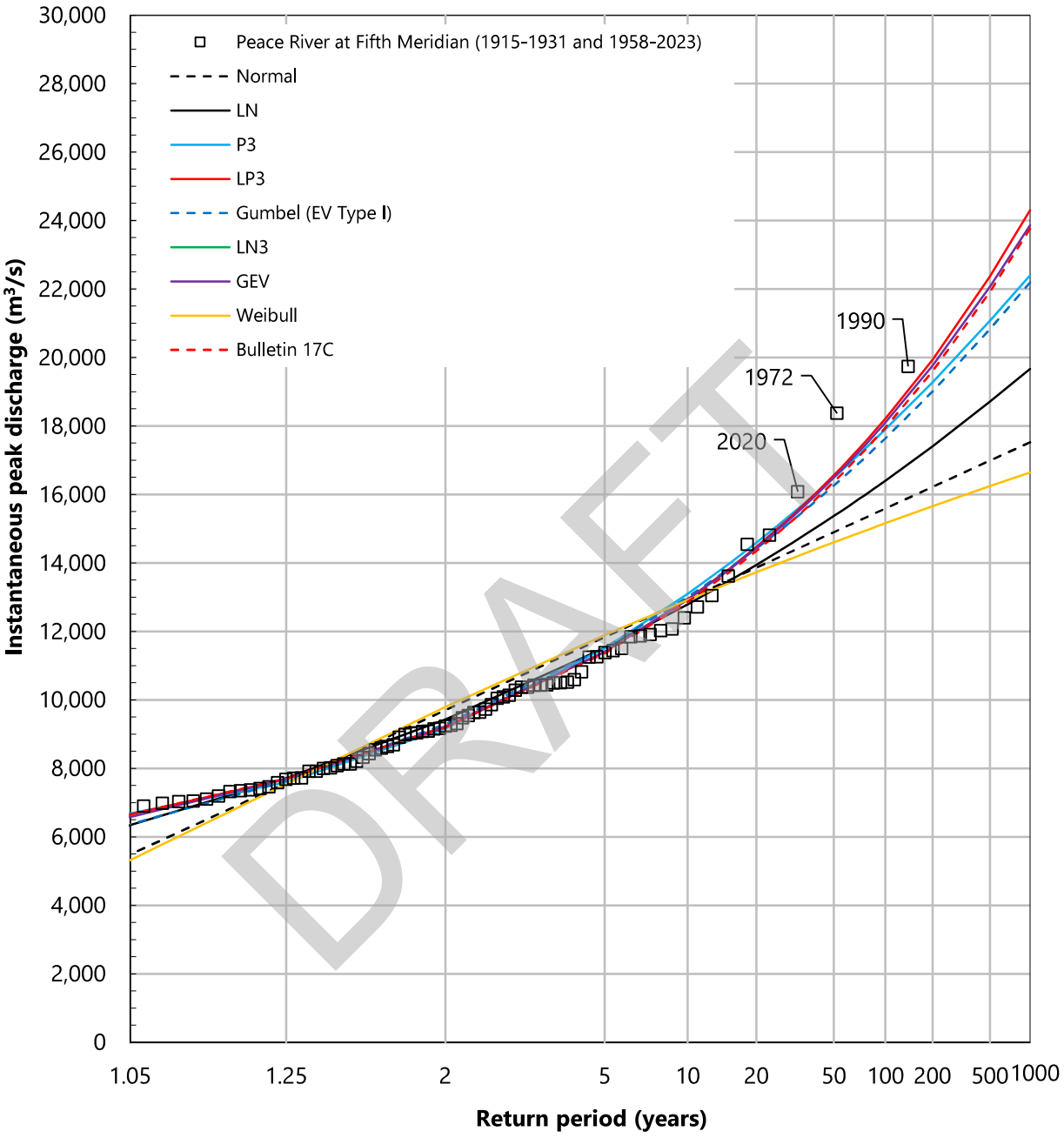
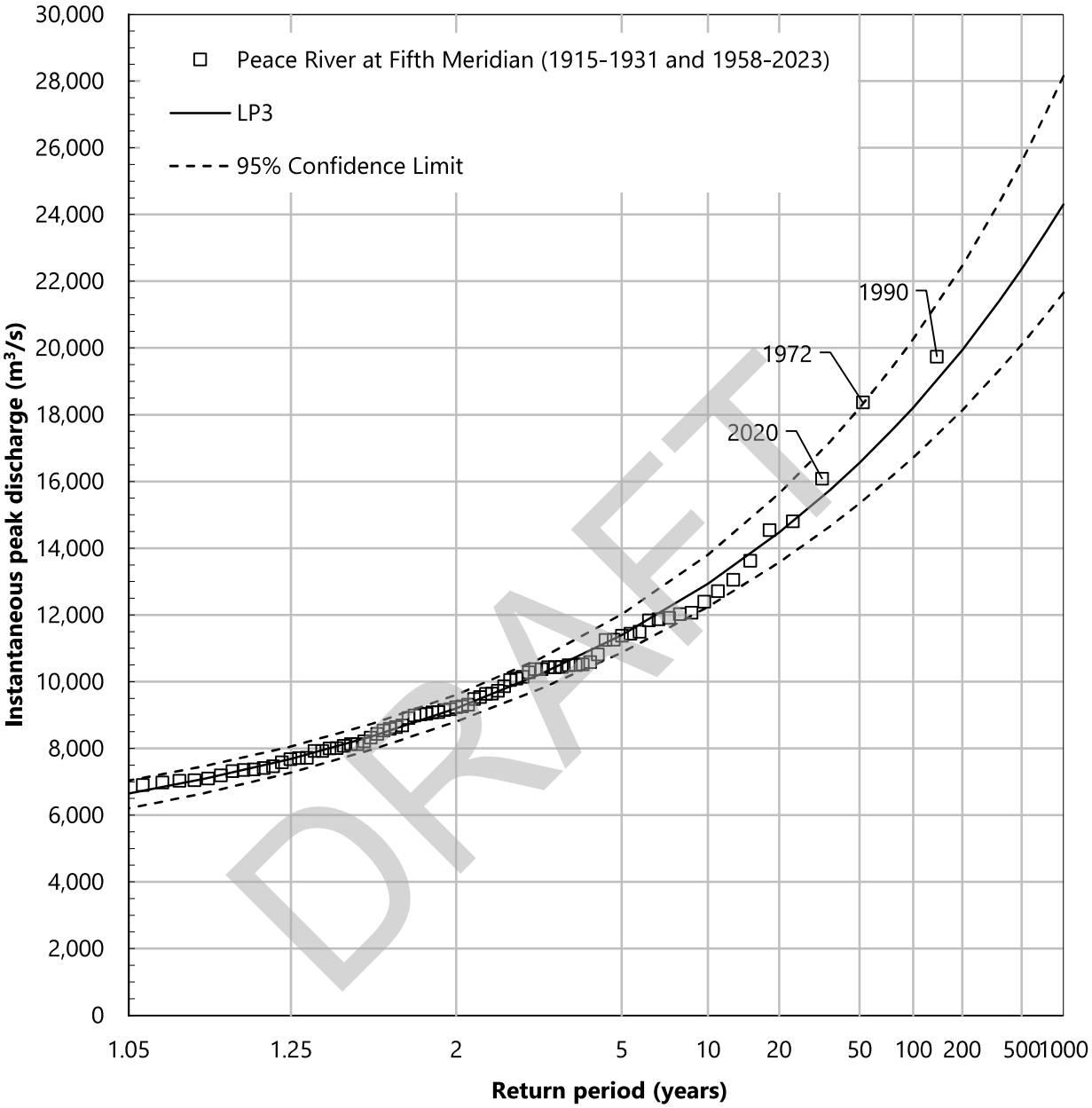


Figure 5.1 Comparison of frequency curves for natural/naturalized Peace River flood peaks at Fifth Meridian

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Figure 5.2 Adopted natural/naturalized flood frequency curve for Peace River at Fifth Meridian

As the gauge data for Peace River at Peace Point (WSC Station 07KC001) were used to correct routed flows at Peace Point, uncertainties in the naturalized flood peaks for Peace Point are expected to be lower than those for Fifth Meridian. So, a flood frequency analysis was also performed for the Peace Point station to provide a comparison. The LP3 distribution was adopted for Peace Point as it provides the best fit for the natural/naturalized flows at this site as

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shown in Figure 5.3. The resulting flood frequency estimates are similar to those for the Fifth Meridian station. The comparison is discussed in Section 6.

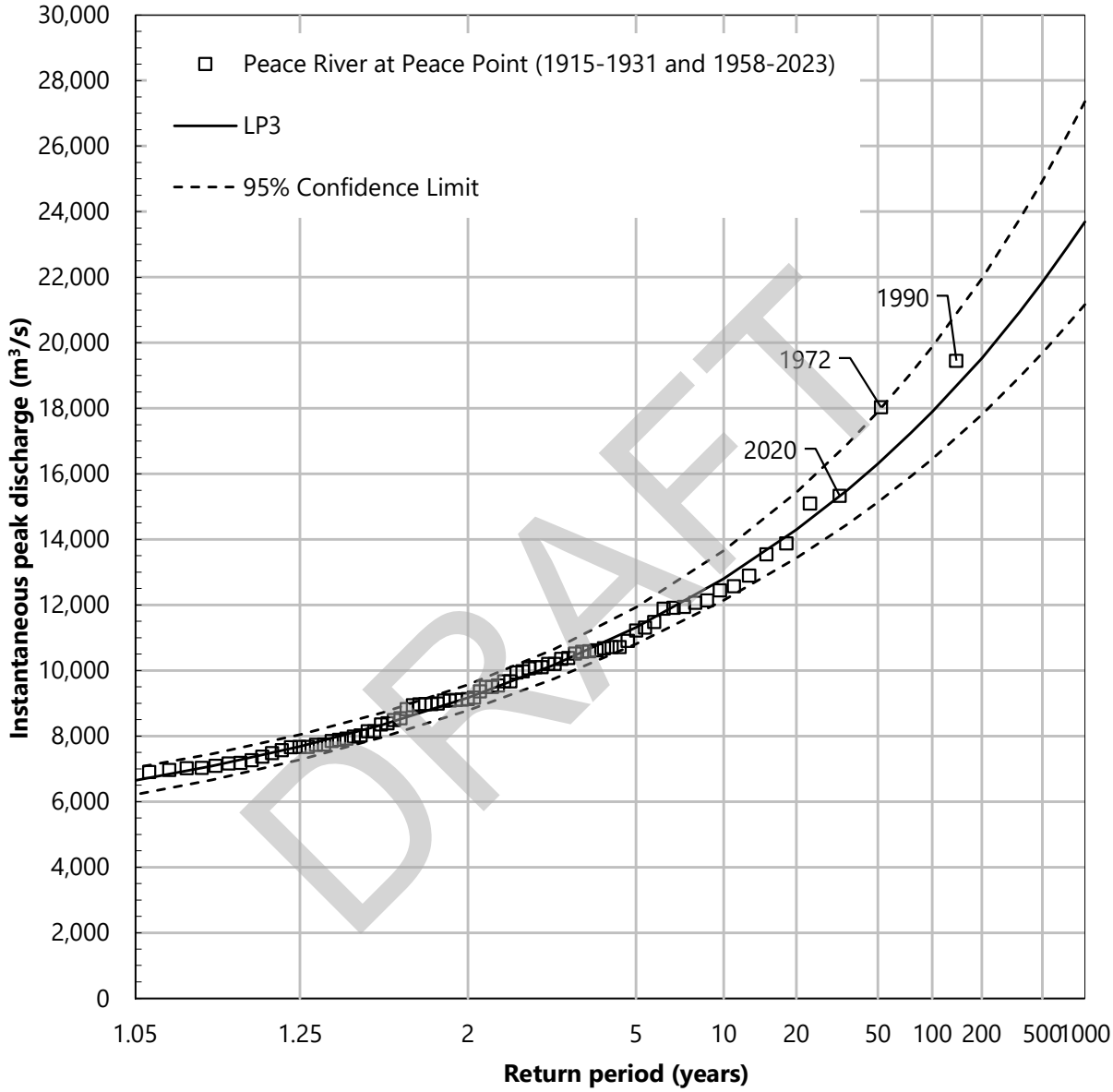


Figure 5.3 Adopted natural/naturalized flood frequency curve for Peace River flood peaks at Peace Point

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5.3 Regional Analysis for Garden Creek

A regional analysis was used to determine flood frequency estimates for Garden Creek because this stream was not gauged.

5.3.1 Regional Streamflow Data Series Preparation

Selection of regional stations for the regional flood frequency analysis involves evaluation of various factors, including, primarily, their proximity to the study area, climate conditions, basin size, length and period of record, natural region, and topography. For this study, six (6) WSC gauge stations were initially considered as candidate regional stations. These gauge stations are listed in Table 3.2. Their locations and drainage areas are shown in Figure 5.4.

After analyzing the available flow data for these candidate stations and reviewing their basin conditions, two were excluded. First, WSC Station 07JC001 (Lafond Creek near Red Earth Creek) was excluded due to its significantly lower runoff potential compared to the other regional basins. This lower runoff potential is likely due to the presence of numerous small depressions, lakes, and potholes in this basin. Second, WSC Station 07JF003 (Ponton River above Boyer River) was excluded. Although the Ponton River basin is near Garden Creek, and the river also originates in the Caribou Mountains, the upper portion of this basin lies on a saucer-shaped plateau. Flows in this river were likely influenced by Margaret Lake, Rocky Island Lake, Caribou Lake, and many smaller lakes. This basin does not appear to be representative of the Garden Creek basin, and its flood peak discharges per unit drainage area are relatively low compared to the other regional stations.

The final selected WSC stations for the regional analysis are listed as follows:

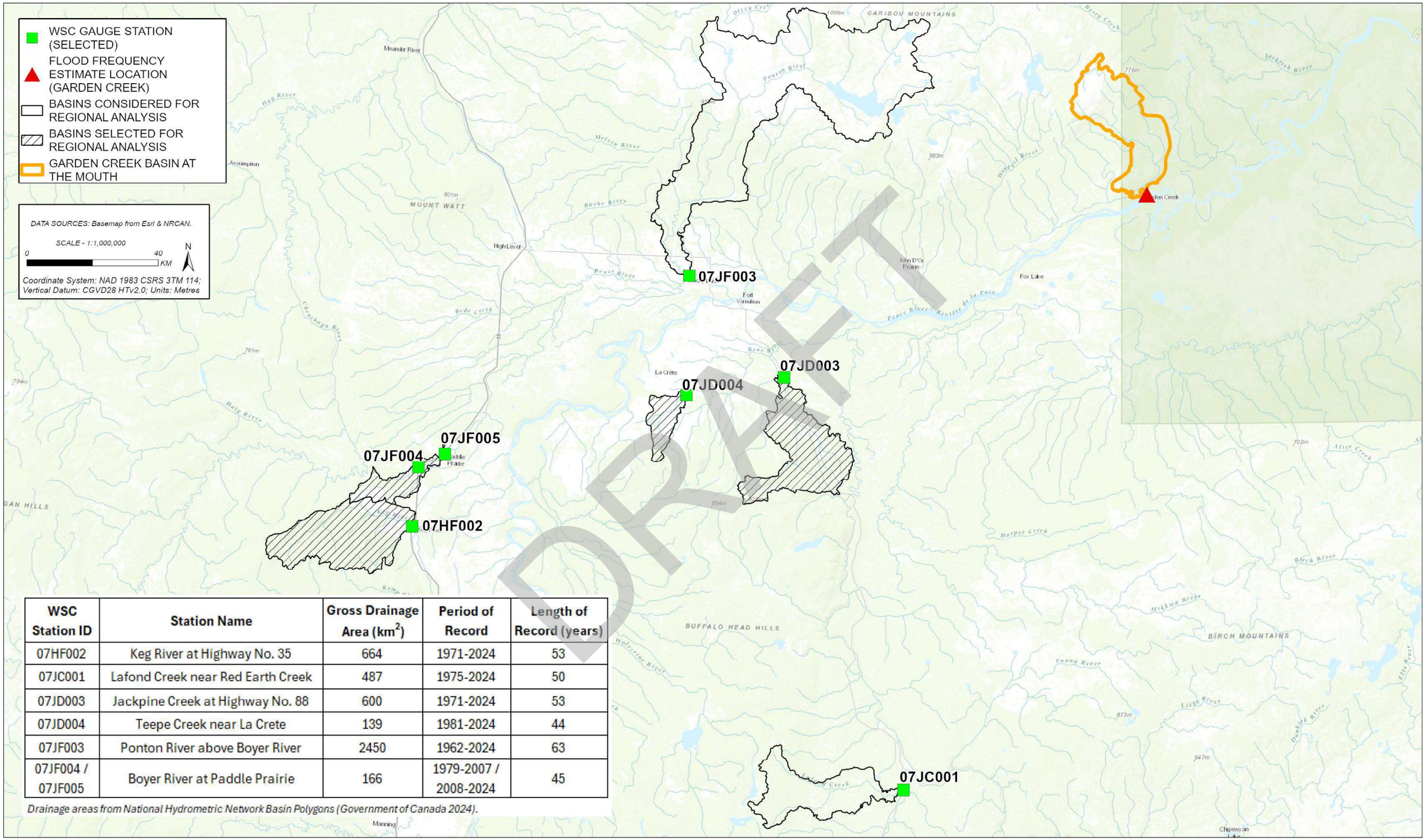
- 07HF002 – Keg River at Highway No. 35
- 07JD003 – Jackpine Creek at Highway No. 88
- 07JD004 – Teepe Creek near La Crete
- 07JF004+07JF005 – Boyer River at Paddle Prairie

Note that the selected regional basins are located to the southwest of the Garden Creek basin and typically receive slightly more precipitation; so, the regional analysis may tend to produce conservatively high flood frequency estimates for Garden Creek.

All data series used for the regional analysis are presented in Appendix A, including annual peak instantaneous discharges and maximum daily discharges for the selected regional stations. All reported annual peak instantaneous values were used in the analysis. For years when peak instantaneous values were missing, they were estimated from the correlations between the instantaneous and daily values for years when both were measured, for the respective stations.

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WSC Station ID	Station Name	Gross Drainage Area (km^2)	Period of Record	Length of Record (years)
07HF002	Keg River at Highway No. 35	664	1971-2024	53
07JC001	Lafond Creek near Red Earth Creek	487	1975-2024	50
07JD003	Jackpine Creek at Highway No. 88	600	1971-2024	53
07JD004	Teepe Creek near La Crete	139	1981-2024	44
07JF003	Ponton River above Boyer River	2450	1962-2024	63
07JF004 / 07JF005	Boyer River at Paddle Prairie	166	1979-2007 / 2008-2024	45

Drainage areas from National Hydrometric Network Basin Polygons (Government of Canada 2024).

Figure 5.4 Regional analysis basin overview

Classification: Public

5.3.2 Regional Flood Frequency Analysis

The frequency distributions in the adopted suite were tested for each individual regional station. Appendix B contains plots of these tested flood frequency distributions. The P3 distribution is among the best in representing the historical flood data of each station. As such, the P3 distribution was selected to develop the regional frequency curve.

The annual peak instantaneous discharges (Q_p) for each of the selected regional stations were normalized by their mean value (Q_{pm}) and are plotted in Figure 5.5 against their empirical return periods (or plotting positions) based on the Cunnane formula. A normalized P3 curve was used to fit the normalized regional flow data. The normalized curve shown in Figure 5.5 was computed by varying the standard deviation and coefficient of skewness within the respective ranges of the values for the selected regional stations, until the sum of the *SSE* values (Equation 2) for the regional stations reached the minimum. The curve fit all regional data points reasonably well. Figure 5.5 also shows the 95% confidence limits for the adopted P3 curve, which were estimated based on the average length of the regional flood data series (48 years).

Figure 5.6 shows the relationship between the mean annual peak discharges (Q_{pm}) and drainage areas for the selected regional stations. It shows that the peak discharge is proportional to drainage area to the power of 0.95. Table 5.3 shows the mean annual peak discharge estimated for Garden Creek with this relationship. Using this estimate and the normalized P3 curve from Figure 5.5, flood frequency estimates were developed for Garden Creek. The resulting flood frequency curve is shown in Figure 5.7.

Table 5.3 Computed mean annual peak discharges for Garden Creek at the mouth

Flood Frequency Estimate Location	Gross Drainage Area (km^2)	Mean Annual Flood Peak (m^3/s)
Garden Creek at the Mouth	590	23.9

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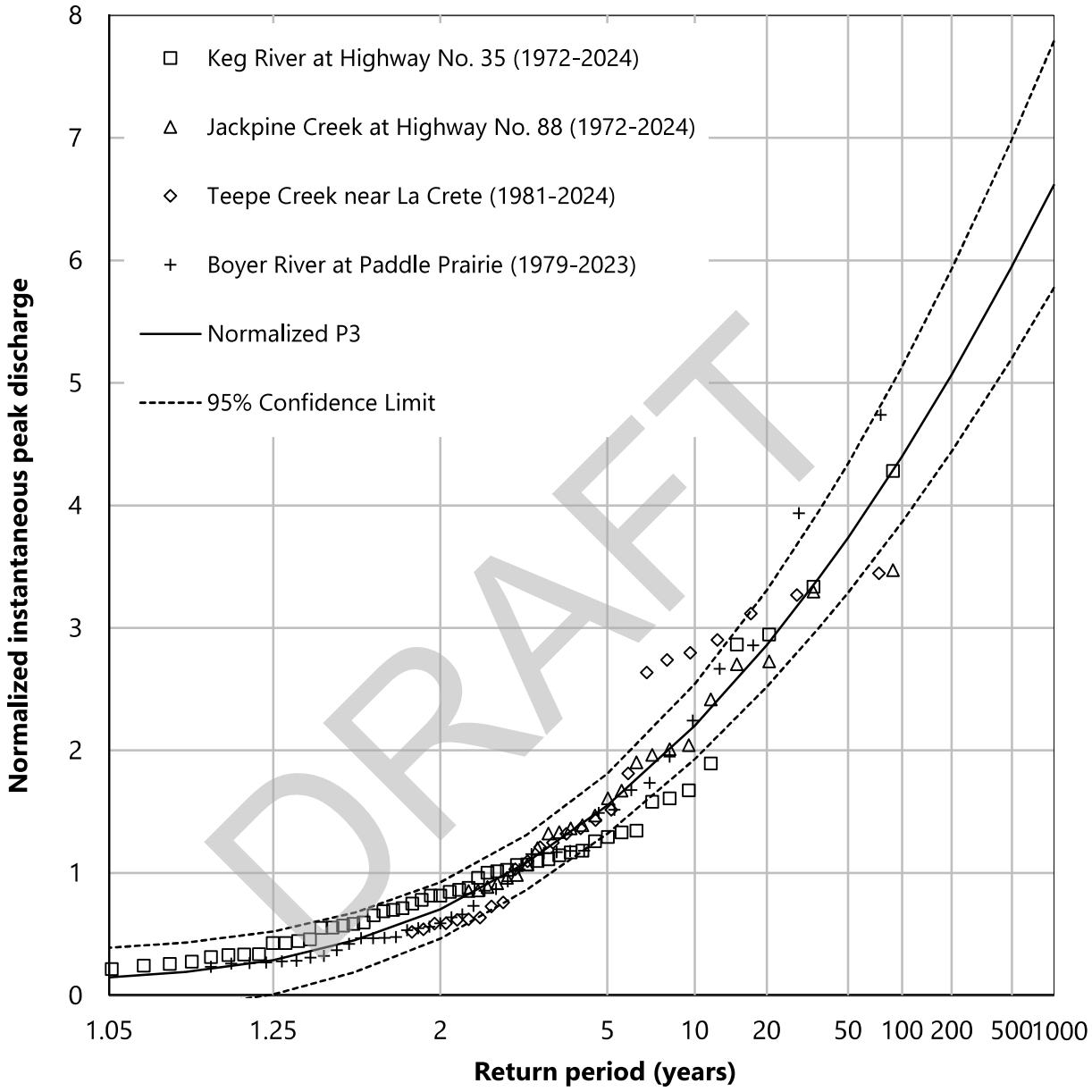


Figure 5.5 Adopted normalized regional P3 flood frequency curve

Classification: Public

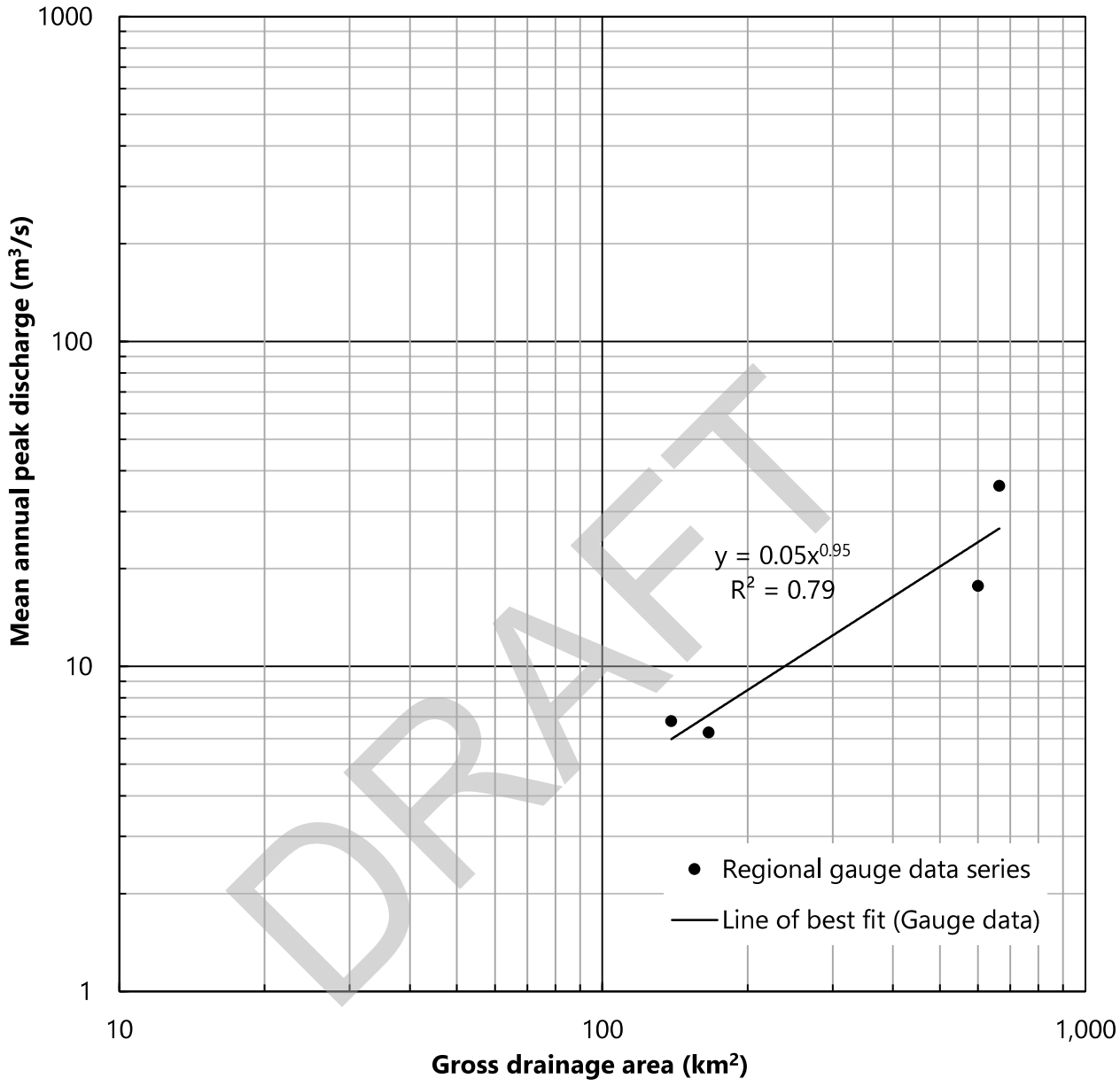


Figure 5.6 Relationship between mean annual peak discharge and drainage Area

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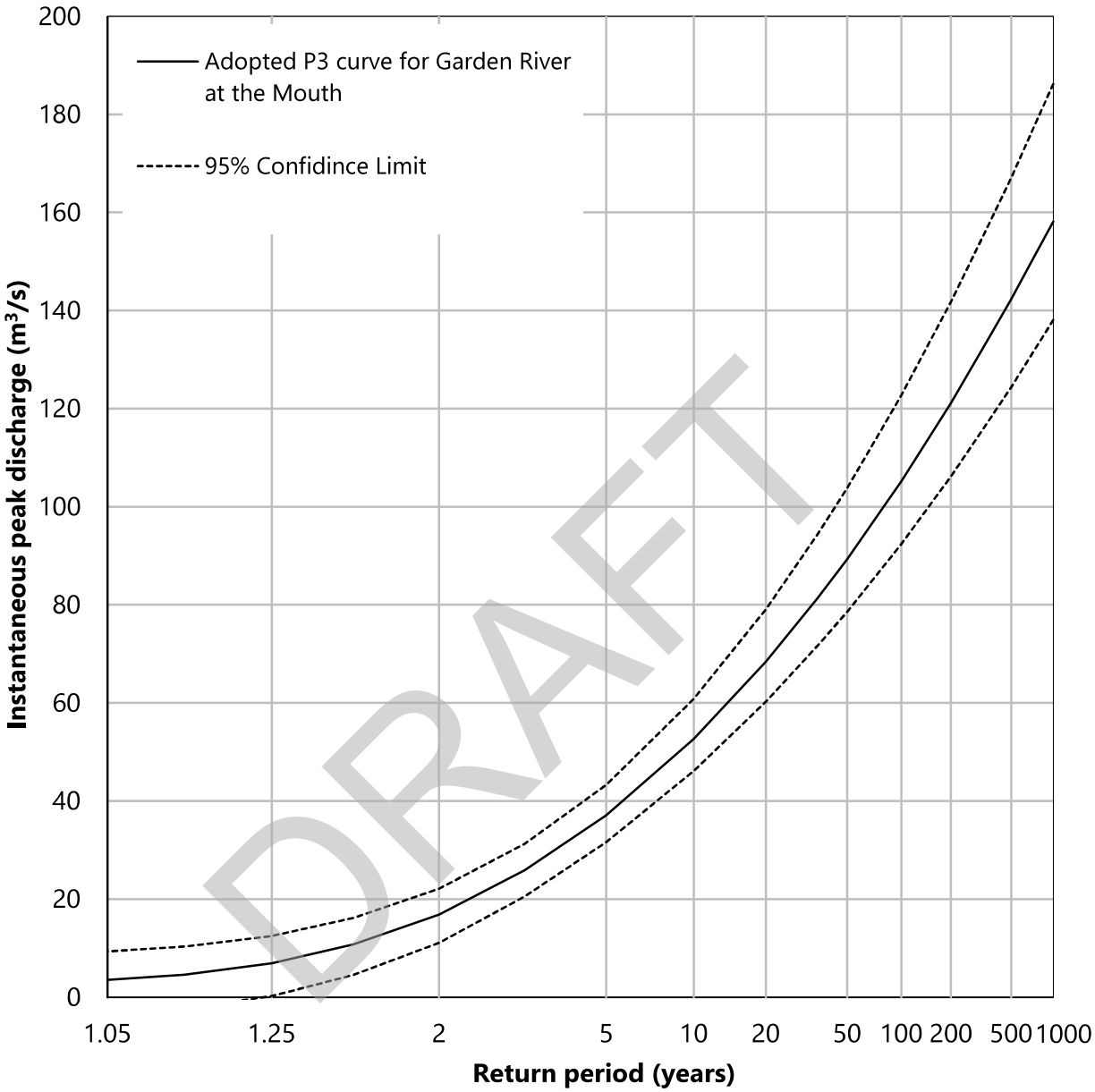


Figure 5.7 Flood frequency curve for Garden Creek at the mouth

Classification: Public

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 floods for Peace River at Fifth Meridian and Garden Creek at the mouth. The results are summarized in Table 6.1. The flood frequency estimates are for the natural and naturalized conditions.

There are no known previous flood frequency estimates for these two sites. NHC (2020) provides flood frequency estimates for Peace River at Fort Vermilion, located 150 km upstream of the study area. In this study, NHC also developed flood frequency estimates for Peace River at Peace Point, located 160 km downstream. These estimates are compared with the estimates for Peace River at Fifth Meridian in Table 6.2. Differences among these three sets of flood frequency estimates are negligible. For return periods longer than 100 years, the estimated flood peak discharges for Fifth Meridian are slightly lower than those for Fort Vermilion and slightly higher than for Peace Point, indicating effects of tributary inflows being offset by attenuations along the river from upstream to downstream. Note that most tributary inflows typically occur between Fort Vermilion and Fifth Meridian, while attenuation in this sub-reach is expected to be less significant than between Fifth Meridian and Peace Point.

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Table 6.1 Flood frequency estimates for Peace River at Fifth Meridian and Garden Creek at the mouth under natural/naturalized conditions

Return Period (years)	Peak Instantaneous Discharge (m^3/s)			
	Peace River at Fifth Meridian		Garden Creek at the mouth	
	Value	Upper 95% Limit Lower 95% limit	Value	Upper 95% Limit Lower 95% limit
1000	24,300	28,200 21,700	158	186 138
750	23,500	27,100 21,000	152	178 133
500	22,400	25,600 20,100	142	167 124
350	21,400	24,400 19,300	134	157 117
200	19,900	22,500 18,100	121	142 106
100	18,200	20,300 16,700	105	123 92.4
75	17,500	19,400 16,200	98.8	115 86.9
50	16,600	18,200 15,300	89.3	104 78.6
35	15,700	17,200 14,700	81.3	94.3 71.6
20	14,500	15,600 13,600	68.4	79.2 60.3
10	12,900	13,800 12,200	52.7	60.9 46.2
5	11,400	12,000 10,900	37.1	43.3 31.6
2	9,200	9,610 8,810	16.8	22.1 11.1

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Table 6.2 Comparison with other relevant flood frequency estimates

Return Period (Years)	Peak Instantaneous Discharge (m^3/s)		
	Peace River at Fort Vermilion (NHC, 2020)	Peace River at Fifth Meridian (This Study)	Peace River at Peace Point (This Study)
1,000	24,700	24,300	23,700
750	23,800	23,500	22,900
500	22,500	22,400	21,800
350	21,500	21,400	20,900
200	19,900	19,900	19,500
100	18,100	18,200	17,900
75	17,300	17,500	17,200
50	16,300	16,600	16,300
35	15,500	15,700	15,500
20	14,100	14,500	14,300
10	12,600	12,900	12,800
5	11,000	11,400	11,300
2	8,830	9,200	9,200

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7 CLIMATE CHANGE COMMENTARY

NHC (2016, 2020) provided a qualitative analysis of climate and hydrologic projections from the scientific literature, relevant to evaluating future flood risks in the Peace River basin. While these assessments were prepared for the upstream study areas, the large-scale climate change assessments are also applicable to downstream Peace River flows. This is because the Peace River open water flood risk at Garden River is primarily governed by runoff from the upper portion of the basin. As such, the climate change commentary for the previous Peace River and Fort Vermilion flood studies are applicable to the Garden River Flood Study. The key points along with additional comments from more recent studies are summarized as follows.

Current global climate models predict that both temperature and precipitation will increase in the upper Peace River basin due to projected increases in carbon dioxide concentrations in the atmosphere. NHC reviewed the statistically downscaled temperature and precipitation data derived from the global climate models of the latest phase of the Coupled Model

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Intercomparison Project (CMIP6) using Plan2Adapt[1]. Under the Shared Socioeconomic Pathway 5-8.5 (SSP 5-8.5) future climate scenario, the annual mean temperature for the Upper Peace River region is projected to increase by 2.7°C and the mean precipitation to increase by 12.9% from the 1981 to 2010 baseline period to the 2041 to 2070 period. The projected temperature and precipitation increases for the 2071 to 2010 period are 5.1°C and 20.8%, respectively.

Poitras et al. (2011) investigated projected changes in average and extreme streamflows of ten major river basins across western Canada, including the Peace River basin. The streamflows were derived from climate simulations performed with the fourth generation of the CRCM forced with the A2 emission scenario (an upper-mid range emission scenario representing a very heterogeneous world where economic development is regionally oriented and economic growth and technological change are relatively slow). The comparisons were made between the 1961 – 1990 period and 2041 – 2070 period. Mean annual flows were projected to increase in all basins, with a 15% increase in the Peace River basin. Changes in extreme flows include higher winter and fall low flows and increased 1-day high flows. Confidence in projected mean annual streamflow changes is higher than in extreme flow projections.

Kerkhoven (2014) analyzed historical data and future projections from General Circulation Models (GCMs) for temperature, precipitation, and river flow. The study utilized Environment Canada's CanGrid dataset, downscaled meteorological data, and future climate projections from the Pacific Climate Impacts Consortium (PCIC). Historical data indicated a significant warming trend of +1.76°C per century and a non-significant increase in precipitation, driven mainly by increased rainfall rather than snowfall. Future projections suggest continued warming with potential acceleration and a range of precipitation changes. Stream flow trends showed a historical decline, inconsistent with the slight increases projected under climate change projections from the PCIC climate change simulation for the upper Peace River Basin. Long-term projections indicate that temperature and precipitation will likely follow the historical trends in future, maintaining the river flow within historical variability but with significant uncertainty due to snowfall variability. Overall, Kerkhoven suggests that river flows are expected to remain in the same range as they have been historically.

Schnorbus and Ben Alaya (2023) present a study to quantify design flood values for the Peace River at TPR for historical and future periods under the changing climate. The study used the second-generation Canadian Earth System – Large Ensemble model (CanESM2-LE) under the Representative Concentration Pathway (RCP) 8.5 emissions scenario to simulate streamflow changes. It provides design flood peak estimates for return periods between 2- and 200-year for a baseline period (1951–2000) and three future periods (2011–2040, 2041–2070, and 2071–2100) based hydrological modelling results from a Variable Infiltration Capacity Gridded (VIC-GL) model. The study showed increases in flood peaks for the 2011–2040 and 2041–2070 periods for

[1] Pacific Climate Impacts Consortium, University of Victoria. Plan2adapt tool. https://services.pacificclimate.org/plan2adapt/app/. Accessed on 28 January 2025.

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Classification: Public

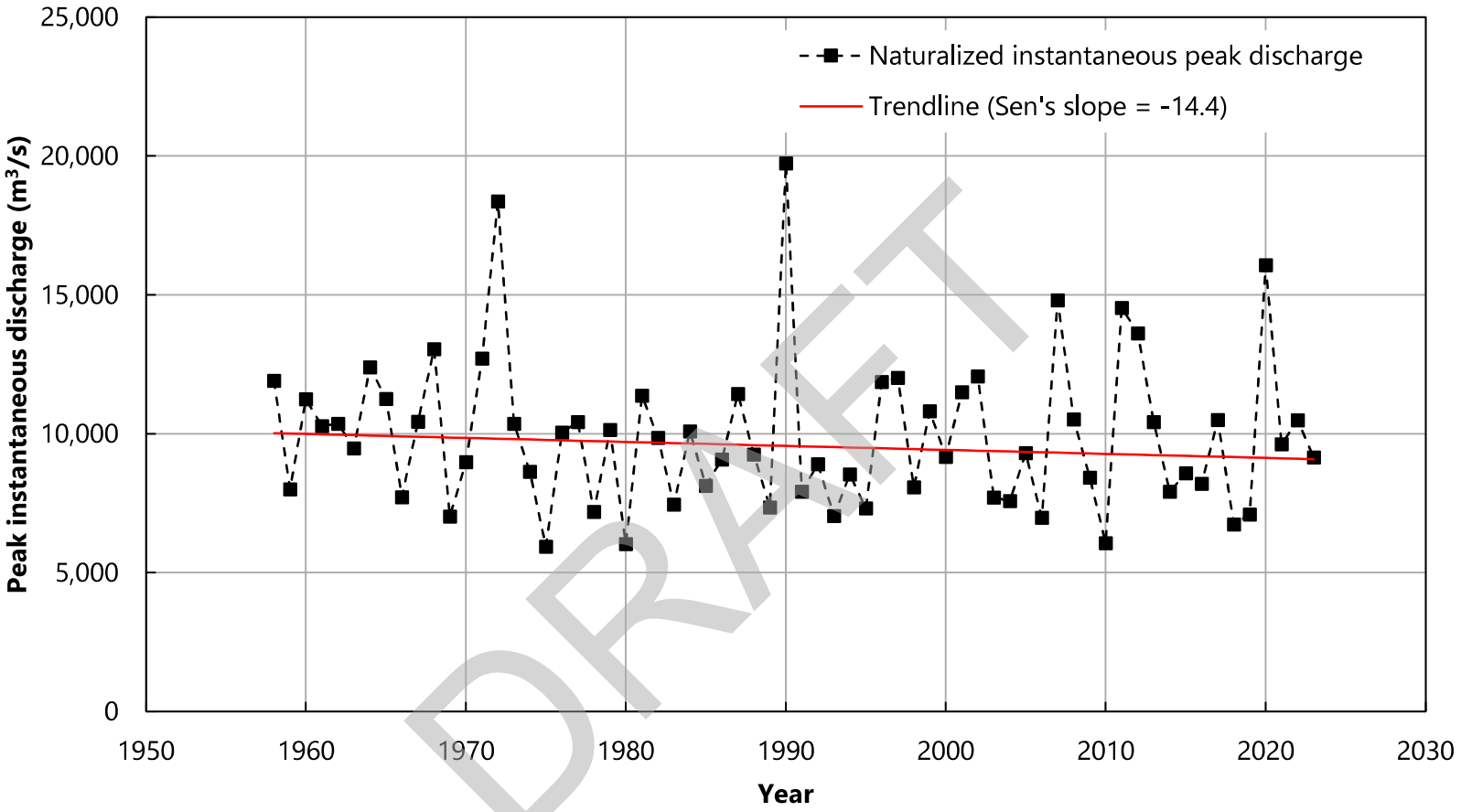
all return periods assessed (2 to 200 years). For the 2071 to 2100 period, the flood peaks for return periods longer than 50 years were projected to increase; but the flood peaks for shorter return periods were projected to decrease. The authors highlighted significant uncertainties in the projected future climate and hydrological modelling results. They acknowledged that simulation of annual maximum peak flow events represents a considerably harder challenge. They also indicates that "it would not perhaps be prudent for an engineer to alter design values from current values based directly on these results, but due diligence presumably imposes the requirement to think seriously about the implications of projected design value changes, even if uncertain".

As part of this assessment, a trend analysis was performed on natural/naturalized annual peak instantaneous flow data for Peace River at Fifth Meridian using the Mann-Kendall (MK) test and Sen's slope. The MK test is a non-parametric statistic test that is commonly used in detecting trends in hydrologic data. Sen's slope is a nonparametric estimate of the slope of a trend. Natural and Naturalized annual instantaneous peak discharges for the 1958-2023 period were used for the trend analysis. The data and trendline based on Sen's slope are shown in Figure 7.1. While the data series appears to have a slightly downward trend based on Sen's slope (which suggests a change rate of -14.4 m^3/s per year), the MK test resulted in a p-value of 0.45, indicating no trend.

Overall, it is highly uncertain whether climate change will lead to more severe or less extreme open water floods on the Peace River.

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Figure 7.1 Trend of annual natural/naturalized peak discharges for Peace River at Fifth Meridian

Classification: Public

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Classification: Public

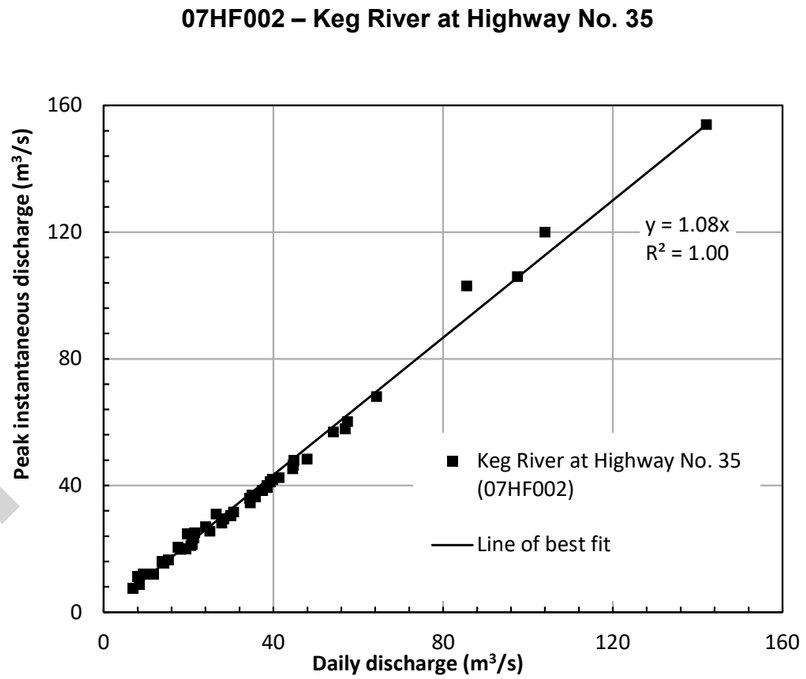
APPENDIX A

FLOW DATA USED FOR REGIONAL ANALYSIS

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Classification: Public

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)
1972	48.40	11-May	47.90	11-May	
1973	42.50	18-Jun	41.30	18-Jun	
1974	56.90	27-Apr	54.10	27-Apr	
1975	27.00	30-Jun	24.00	29-Jun	
1976	34.50	29-Jun	34.50	28-Jun	
1977	103.00	04-Jun	85.50	04-Jun	
1978	36.00	01-May	34.30	01-May	
1979	41.20	29-May	39.40	02-Jun	39.30
1980	7.55	26-May	6.95	26-May	
1981	40.00	03-May	38.50	03-May	
1982	23.50	05-May	21.10	05-May	
1983	16.50	16-Jul	15.20	17-Jul	
1984	30.40	02-Jul	29.90	02-Jul	
1985	28.10	06-May	27.80	05-May	
1986	15.40	22-Jun	14.00	23-Jun	
1987	154.00	03-Aug	142.00	03-Aug	
1988	16.00	02-Jul	13.80	02-Jul	
1989	38.30	02-May	37.30	02-May	
1990	57.90	14-Jun	56.90	14-Jun	
1991	120.00	16-Jun	104.00	16-Jun	
1992	29.30	02-May	28.20	02-May	
1993	**38.45**		35.60	25-Jun	
1994	19.90	23-Apr	19.40	23-Apr	
1995	11.90	28-Apr	10.50	24-Apr	10.10
1996	31.60	21-Jun	30.60	21-Jun	
1997	47.90	02-Aug	44.80	02-Aug	
1998	24.70	15-Jul	19.60	15-Jul	
1999	8.77	15-Jul	8.23	15-Jul	
2000	25.60	25-May	25.00	25-May	
2001	21.00	07-May	20.50	07-May	
2002	12.10	21-May	11.50	21-May	
2003	25.10	23-Apr	21.40	23-Apr	
2004	**7.77**		7.19	28-Jul	
2005	42.00	24-Apr	39.80	23-Apr	
2006	20.50	05-Aug	17.50	05-Aug	
2007	36.90	07-May	34.90	07-May	
2008	39.50	23-May	38.50	23-May	
2009	19.80	21-Jul	18.10	21-Jul	
2010	21.40	27-May	20.80	27-May	
2011	68.10	11-Jul	64.30	11-Jul	
2012	11.30	29-Apr	8.04	29-Apr	
2013	45.30	15-May	44.50	15-May	
2014	29.30	02-May	28.20	02-May	
2015	**9.93**		9.19	02-Apr	
2016	36.50	18-Jun	35.70	18-Jun	
2017	12.00	15-May	11.70	15-May	
2018	46.50	14-Jun	44.70	14-Jun	
2019	15.40	27-Jul	14.10	27-Jul	
2020	60.20	06-Jul	57.40	06-Jul	
2021	31.00	18-Jun	26.50	19-Jun	
2022	106.00	30-May	97.50	30-May	
2023	4.06	03-May	3.67	03-May	
2024	**9.30**		8.61	15-Jun	



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Notes:
1. The bolded and underlined values are based on Qp=1.08Qd.
2. Data for 2024 is preliminary from WSC

SCALE – AS SHOWN

Coordinate System:
Units: As Shown

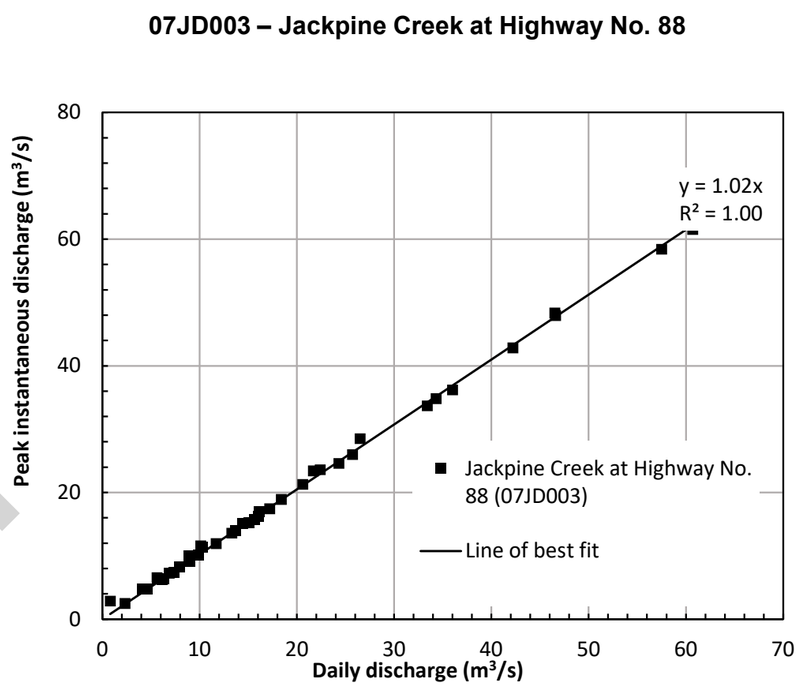
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GARDEN RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
KEG RIVER AT HIGHWAY NO. 35
MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-1

Classification: Public

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)
1972	34.80	05-May	34.30	05-May	
1973	42.80	28-Jul	42.20	29-Jul	
1974	36.20	23-Apr	36.00	23-Apr	
1975	33.70	03-Sep	33.40	03-Sep	
1976	23.60	02-Jul	22.40	02-Jul	
1977	13.60	10-Jun	13.30	10-Jun	
1978	10.10	30-May	9.88	29-May	
1979	28.50	02-May	26.50	02-May	
1980	4.71	30-Jul	4.57	30-Jul	
1981	10.00	01-May	9.07	05-May	8.86
1982	6.27	02-May	6.16	05-May	6.11
1983	9.17	25-Apr	8.98	26-Apr	
1984	17.40	08-Jul	17.20	08-Jul	
1985	16.20	09-May	16.00	09-May	
1986	47.90	23-Jun	46.60	24-Jun	
1987	48.30	05-Aug	46.50	05-Aug	
1988	23.40	19-Apr	21.70	19-Apr	
1989	26.00	04-May	25.70	04-May	
1990	15.70	27-Apr	15.60	27-Apr	
1991	61.50	18-Jun	60.70	18-Jun	
1992	15.20	29-Sep	15.10	29-Sep	
1993	**24.17**		23.70	29-Jun	
1994	11.60	16-Apr	10.20	18-Apr	10.10
1995	11.40	30-Apr	10.30	30-Apr	
1996	58.40	22-Jun	57.50	23-Jun	
1997	24.60	03-Oct	24.30	03-Oct	
1998	**9.82**		9.63	14-Apr	
1999	2.84	27-Apr	1.18	28-May	0.84
2000	6.35	04-Sep	6.29	04-Sep	
2001	11.90	12-May	11.70	12-May	
2002	4.68	11-Sep	4.14	12-Sep	
2003	7.41	27-Apr	7.32	28-Apr	
2004	6.35	11-Apr	5.63	12-Apr	
2005	17.00	15-Apr	16.10	14-Apr	
2006	15.10	17-Jul	14.40	17-Jul	
2007	14.00	10-May	13.70	10-May	
2008	6.56	31-May	5.77	08-May	5.61
2009	**7.59**		7.44	19-Apr	
2010	8.26	27-Apr	7.94	27-Apr	
2011	18.90	15-Jul	18.40	15-Jul	
2012	2.45	20-Jul	2.32	20-Jul	
2013	21.30	17-May	20.60	17-May	
2014	7.23	06-May	6.85	06-May	
2015	**2.05**		2.01	18-Apr	
2016	1.89	28-Jun	1.22	28-Jun	
2017	4.46	15-May	4.13	21-May	2.56
2018	29.60	17-Jun	28.80	17-Jun	
2019	3.66	20-Aug	2.55	17-Sep	2.46
2020	**13.16**		12.90	25-Apr	
2021	12.30	13-May	11.90	13-May	
2022	35.60	02-Jun	35.10	11-May	34.70
2023	**3.02**		2.96	24-Apr	
2024	**10.03**		9.83	04-Jun	



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Notes:
1. The bolded and underlined values are based on Qp=1.02Qd.
2. Data for 2024 is preliminary from WSC.

SCALE – AS SHOWN

Coordinate System:
Units: As Shown

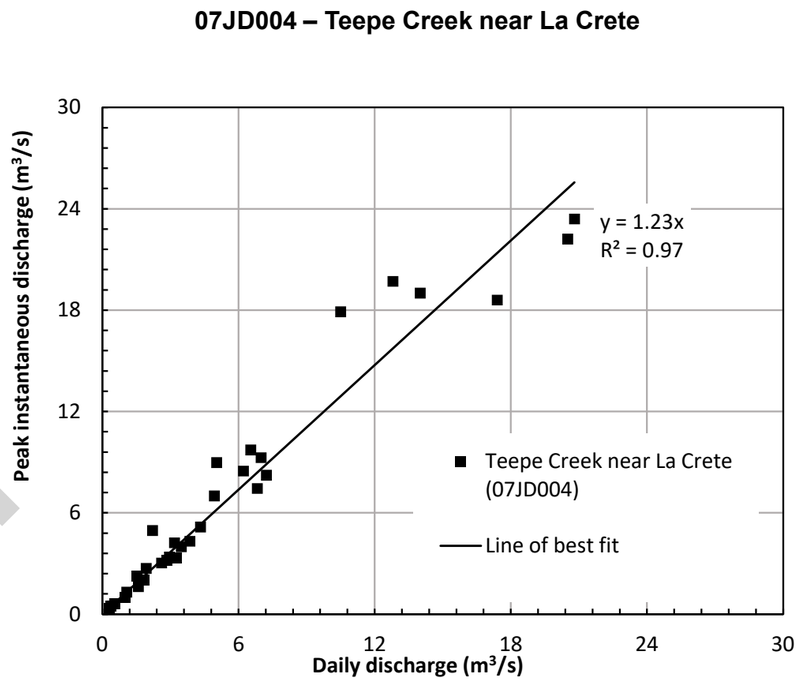
Job: 1009251 | *Date: 31-JAN-2025*

GARDEN RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
JACKPINE CREEK AT HIGHWAY NO. 88 MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-2

Classification: Public

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)
1981	1.63	30-Apr	1.58	30-Apr	
1982	2.26	22-Apr	1.53	22-Apr	
1983	8.96	19-Apr	5.03	19-Apr	
1984	1.00	07-Jul	0.98	07-Jul	
1985	4.94	02-Apr	2.21	02-Apr	
1986	3.31	25-Jun	3.25	25-Jun	
1987	23.40	16-Apr	20.80	16-Apr	
1988	8.22	17-Apr	7.23	17-Apr	
1989	3.38	13-Apr	2.95	14-Apr	
1990	9.72	19-Apr	6.53	19-Apr	
1991	3.99	05-Apr	3.47	06-Apr	
1992	2.01	01-Mar	1.84	01-Mar	
1993	**0.17**		0.14	08-May	
1994	7.00	30-Mar	4.93	30-Mar	
1995	**4.00**		3.25	23-Apr	
1996	8.47	17-Apr	6.21	18-Apr	
1997	19.00	19-Apr	14.00	19-Apr	
1998	**3.53**		2.87	05-Apr	
1999	0.34	13-Apr	0.29	13-Apr	
2000	**1.18**		0.96	04-Apr	
2001	0.63	14-Apr	0.55	15-Apr	
2002	**0.01**		0.01	26-Apr	
2003	**3.67**		2.98	13-Apr	
2004	**10.30**		8.37	05-Apr	
2005	**12.30**		10.00	11-Apr	
2006	**0.77**		0.62	08-Apr	
2007	9.26	11-Apr	6.99	11-Apr	
2008	19.70	15-Apr	12.80	15-Apr	
2009	7.44	14-Apr	6.82	15-Apr	
2010	**4.19**		3.41	02-Apr	
2011	5.15	11-Apr	4.32	11-Apr	
2012	1.29	31-Mar	1.07	31-Mar	
2013	22.20	04-May	20.50	05-May	
2014	4.22	10-Apr	3.17	10-Apr	
2015	3.03	01-Apr	2.61	01-Apr	
2016	3.19	17-Apr	2.83	17-Apr	
2017	0.48	02-Apr	0.38	01-Apr	
2018	17.90	23-Apr	10.50	23-Apr	
2019	**1.55**		1.26	28-Mar	
2020	4.32	21-Apr	3.85	21-Apr	
2021	**21.16**		17.20	16-Apr	
2022	18.60	01-May	17.60	29-Apr	17.60
2023	2.70	13-Apr	1.93	13-Apr	
2024	**1.43**		1.16	12-Apr	



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

SCALE – AS SHOWN

Coordinate System:
Units: As Shown

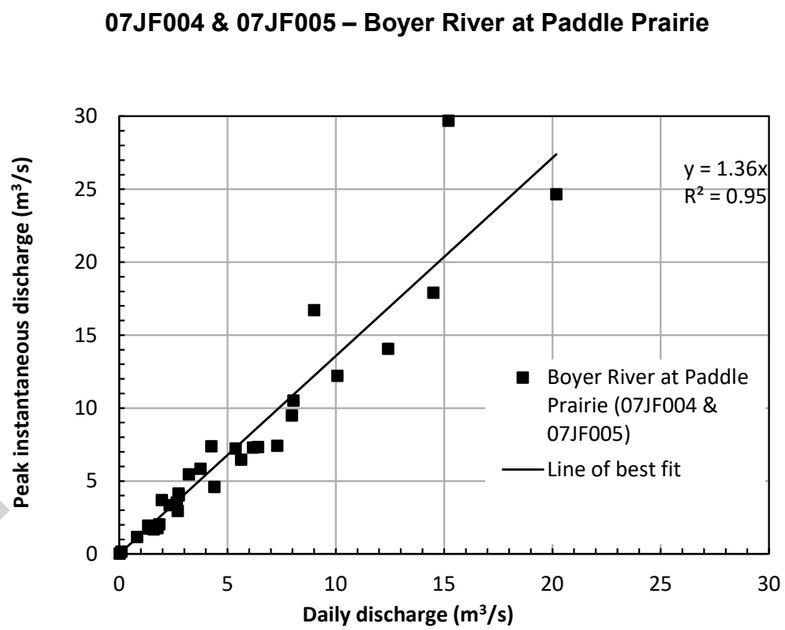
Job: 1009251 | *Date: 31-JAN-2025*

GARDEN RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
TEEPE CREEK NEAR LA CRETE
MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-3

Classification: Public

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)
1979	24.67	01-May	20.18	01-May	
1980	0.15	18-Apr	0.12	15-Apr	0.10
1981	12.22	27-Apr	10.07	27-Apr	
1982	2.03	28-Apr	1.85	28-Apr	
1983	5.84	20-Apr	3.75	21-Apr	
1984	0.03	30-Jun	0.02	30-Jun	
1985	7.39	04-Apr	4.25	04-Apr	
1986	3.34	09-Apr	2.33	09-Apr	
1987	10.51	13-Apr	8.04	13-Apr	
1988	5.45	14-Apr	3.21	15-Apr	
1989	16.71	12-Apr	8.99	13-Apr	
1990	4.59	19-Apr	4.50	09-Apr	4.39
1991	4.15	05-Apr	2.73	06-Apr	
1992	7.23	01-Mar	5.37	01-Mar	
1993	**2.99**		2.20	12-Aug	
1994	1.94	30-Mar	1.60	17-Apr	1.34
1995	**10.87**		7.99	24-Apr	
1996	2.95	22-Apr	2.70	22-Apr	
1997	14.06	23-Apr	12.42	23-Apr	
1998	**1.62**		1.19	03-Apr	
1999	1.68	19-Apr	1.59	19-Apr	
2000	**0.84**		0.62	07-Apr	
2001	1.77	19-Apr	1.77	19-Apr	
2002	**2.92**		2.15	24-Apr	
2003	6.45	19-Apr	5.62	19-Apr	
2004	1.74	02-Apr	1.40	03-Apr	
2005	3.69	22-Apr	1.97	22-Apr	
2006	**5.36**		3.94	12-Apr	
2007	**9.34**		6.87	16-Apr	
2008	**7.41**		7.30	30-Apr	
2009	9.49	18-Apr	7.97	18-Apr	
2010	3.52	04-Apr	2.65	05-Apr	
2011	7.29	26-Apr	6.18	26-Apr	
2012	**3.44**		2.53	12-Apr	
2013	29.70	06-May	15.20	07-May	
2014	7.33	11-Apr	6.41	11-Apr	
2015	4.00	05-Apr	2.75	06-Apr	
2016	**1.66**		1.22	11-Apr	
2017	**0.94**		0.69	10-Apr	
2018	1.17	27-Apr	0.83	27-Apr	
2019	**1.47**		1.08	27-Mar	
2020	**2.92**		2.15	20-Apr	
2021	**2.31**		1.70	17-Apr	
2022	17.90	31-May	14.50	31-May	
2023	**2.64**		1.94	15-Apr	
2024	DRY				



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Notes:
1. The bolded and underlined values are based on Qp=1.36Qd.
2. Data for 2024 is preliminary from WSC.
3. The flood peak record for WSC Station 07JF005 – Boyer River at Paddle Prairie was extended using available data from the adjacent discontinued WSC Station 07JF004 – Boyer River near paddle Prairie.

SCALE – AS SHOWN

Coordinate System:
Units: As Shown

Job: 1009251 | *Date: 31-JAN-2025*

GARDEN RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT
BOYER RIVER AT PADDLE PRAIRIE MAXIMUM INSTANTANEOUS TO DAILY DISCHARGE COMPARISON

FIGURE A-4

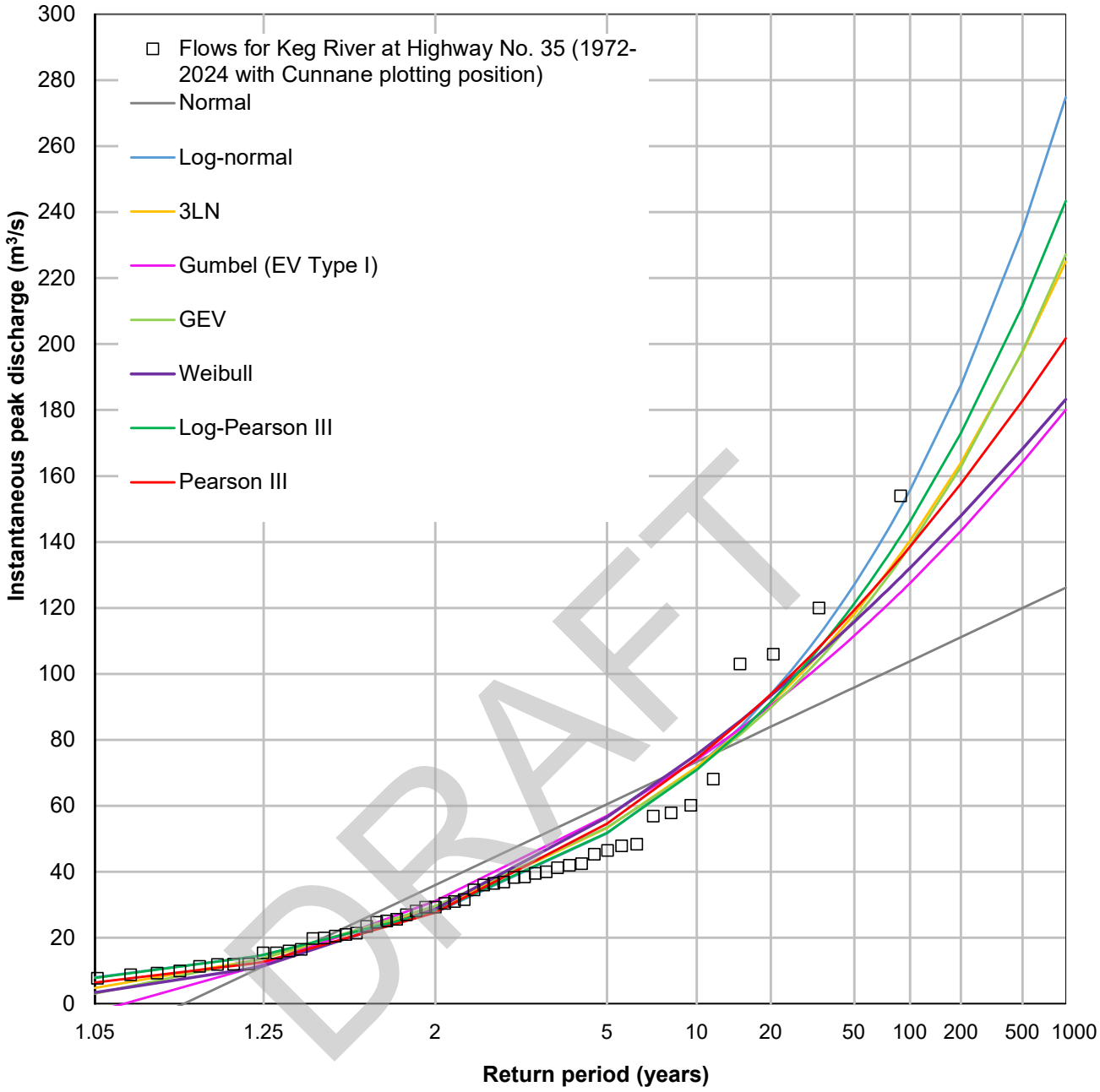
Classification: Public

APPENDIX B

FLOOD FREQUENCY ANALYSIS FOR REGIONAL STATIONS

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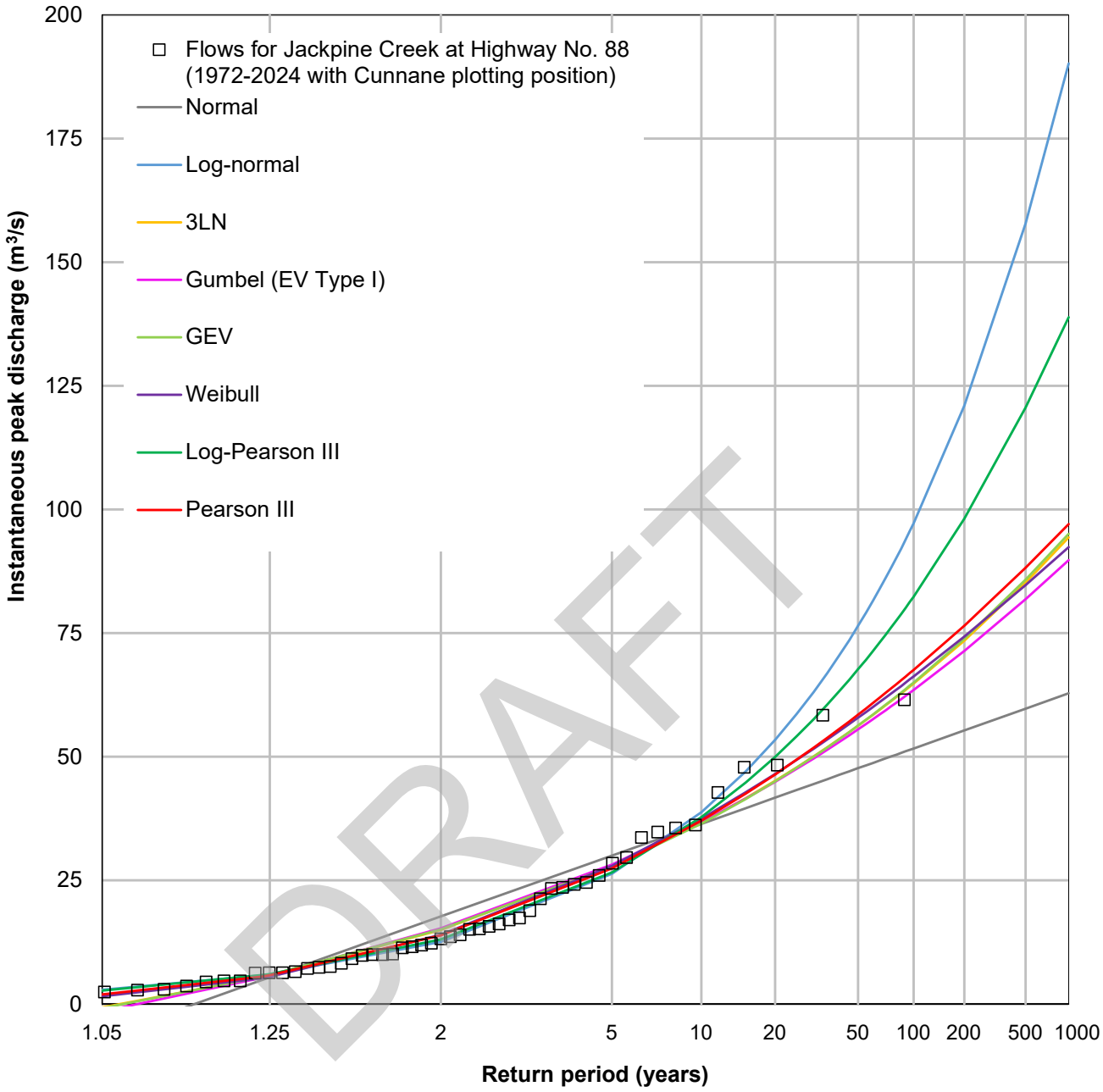
Classification: Public



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Alberta Canada	SCALE – AS SHOWN	GARDEN RIVER FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
nhc	Coordinate System: Units: As Shown	**FLOOD FREQUENCY CURVES FOR KEG RIVER AT HIGHWAY NO. 35**
	Job: 1009251 / *Date: 31-JAN-2025*	FIGURE B-1

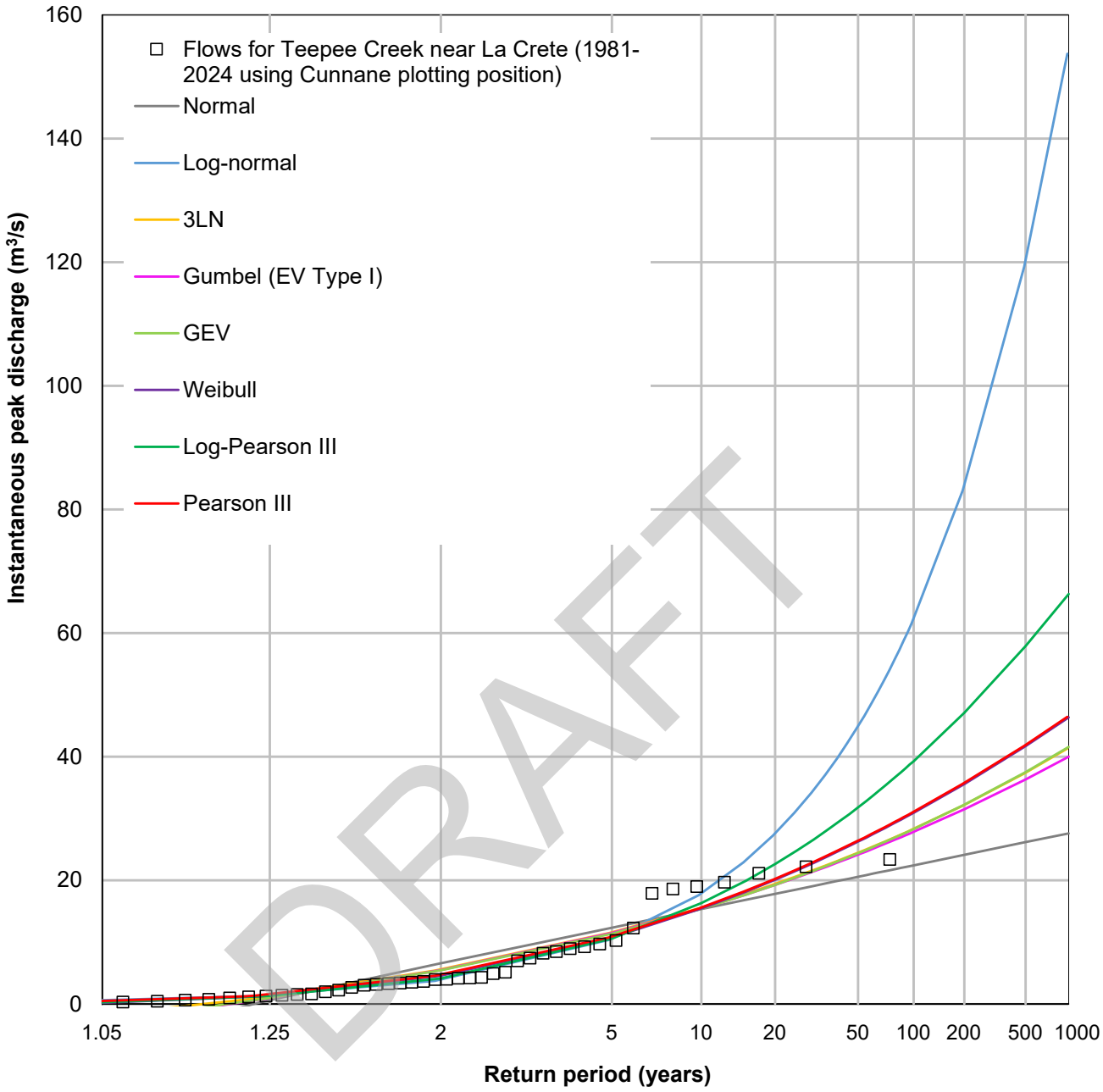
Classification: Public



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Alberta Canada	SCALE – AS SHOWN	GARDEN RIVER FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
nhc	Coordinate System: Units: As Shown	**FLOOD FREQUENCY CURVES FOR JACKPINE CREEK AT HIGHWAY NO. 88**
	Job: 1009251 / *Date: 31-JAN-2025*	FIGURE B-2

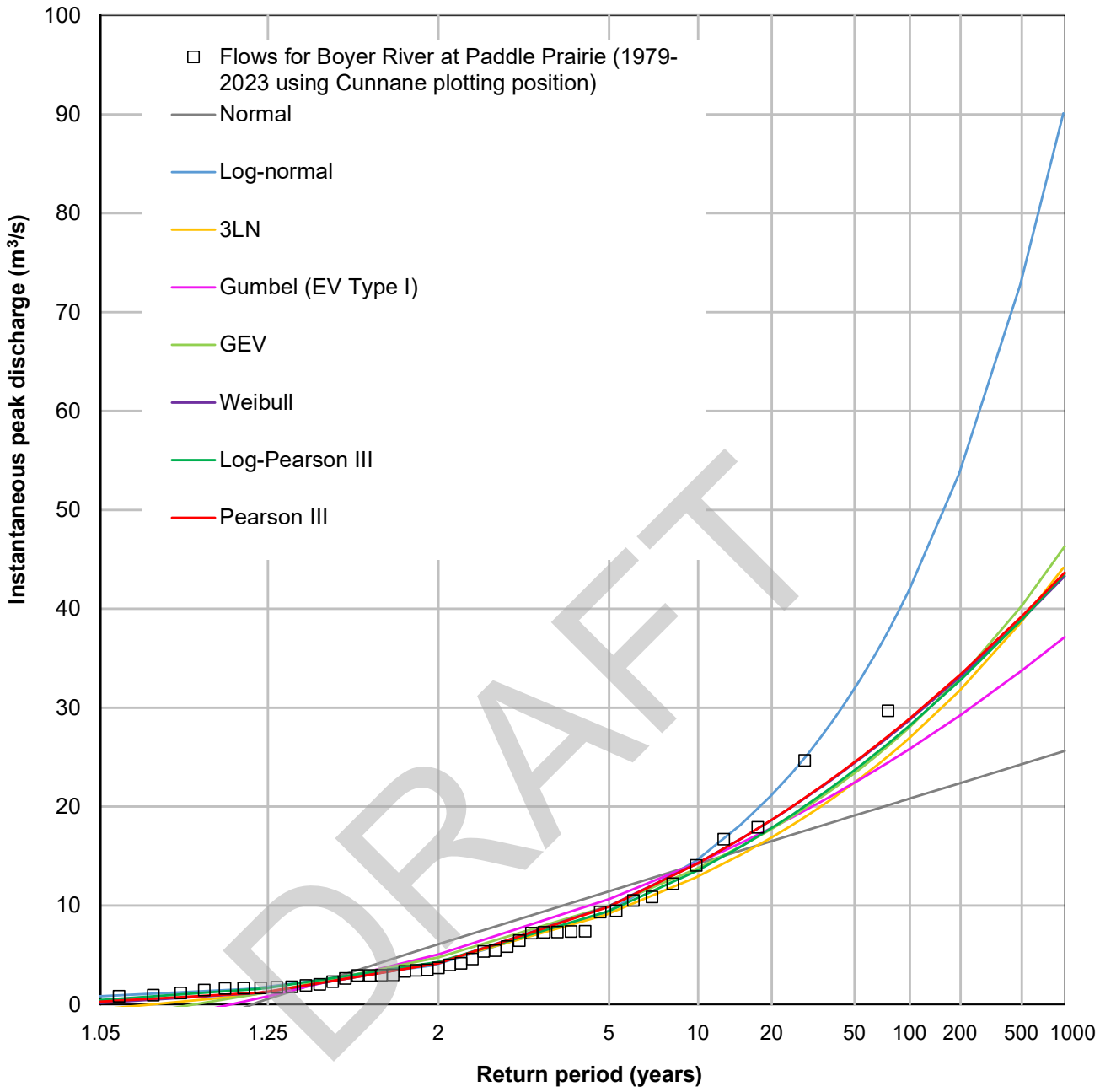
Classification: Public



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Alberta Canada / nhc	SCALE – AS SHOWN	GARDEN RIVER FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
	Coordinate System: Units: As Shown	**FLOOD FREQUENCY CURVES FOR TEEPEE CREEK NEAR LA CRETE**
	Job: 1009251 / *Date: 31-JAN-2025*	FIGURE B-3

Classification: Public



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Alberta Canada	SCALE – AS SHOWN	GARDEN RIVER FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT
nhc	Coordinate System: Units: As Shown	**FLOOD FREQUENCY CURVES FOR BOYER RIVER AT PADDLE PRAIRIE**
	Job: 1009251 / *Date: 31-JAN-2025*	FIGURE B-4

Classification: Public

APPENDIX B

SURVEY OVERVIEW

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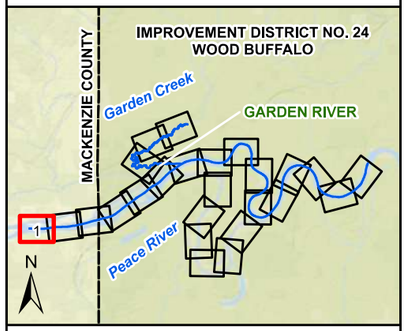
Classification: Public



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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- COUNTY DISTRICT
- SURVEY CROSS SECTION
- SURVEY POINT
- CONTROL POINT
- ICE SCAR
- DEBRIS PILE

SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

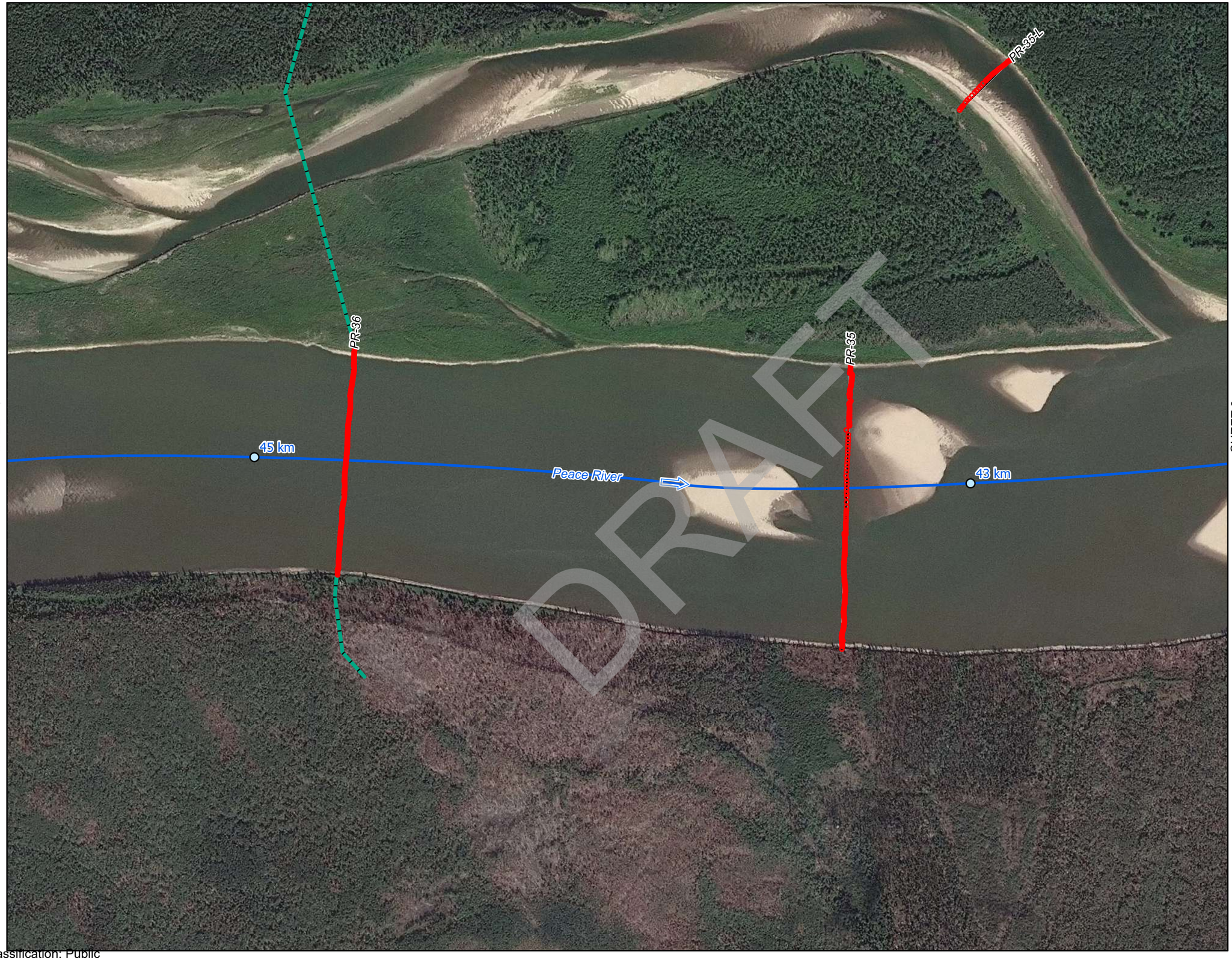
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 1 OF 25

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Classification: Public



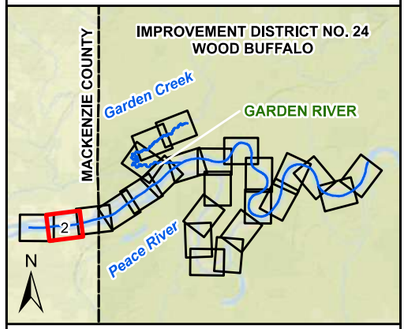
SHEET 1

SHEET 3

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

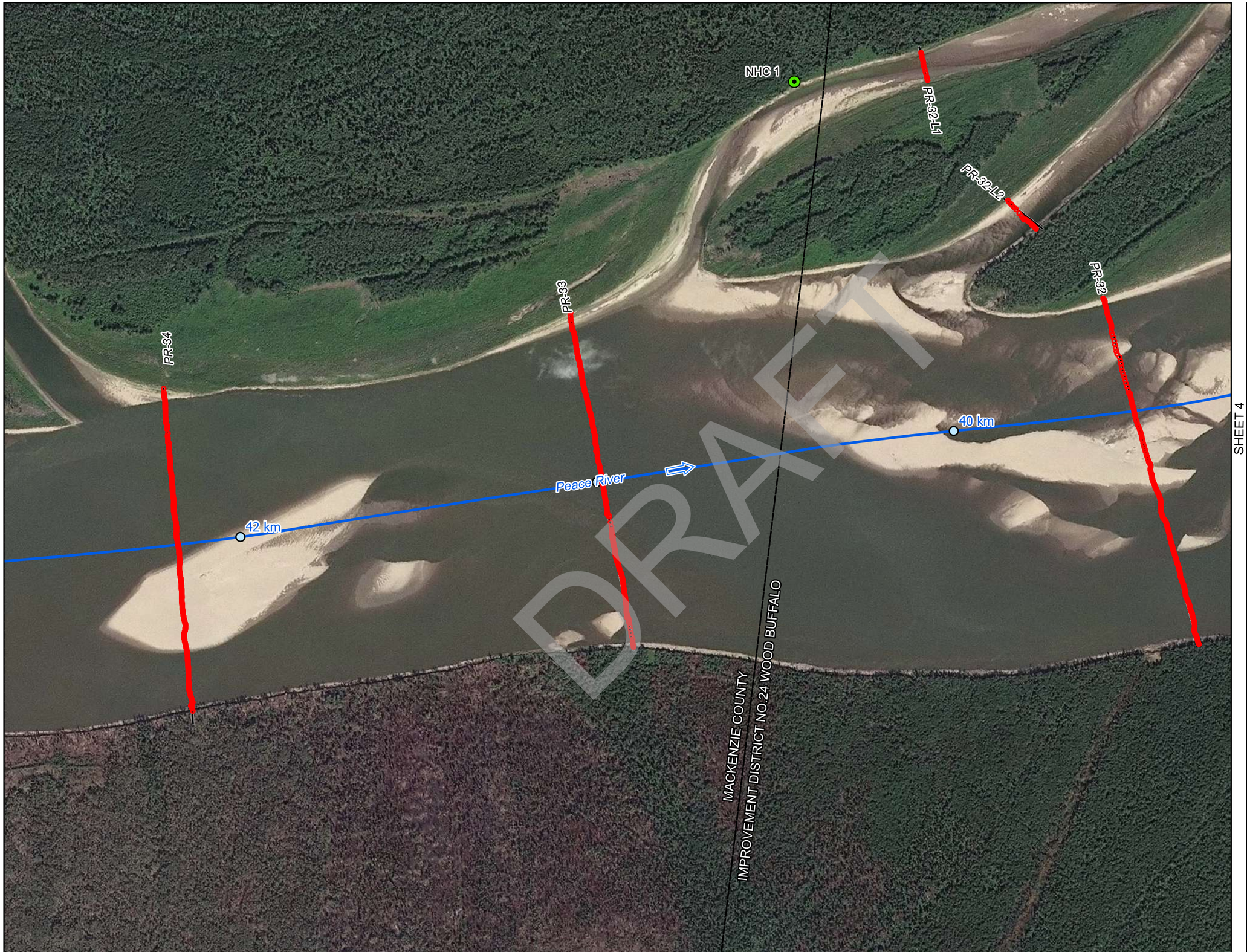
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 2 OF 25

Classification: Public

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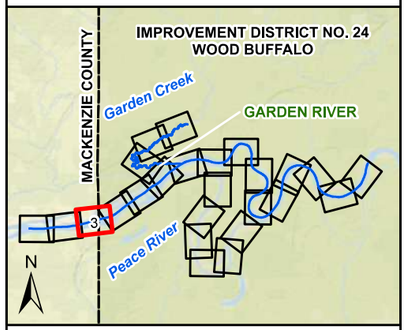


SHEET 2

SHEET 4

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- MAJOR HIGHWAY
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
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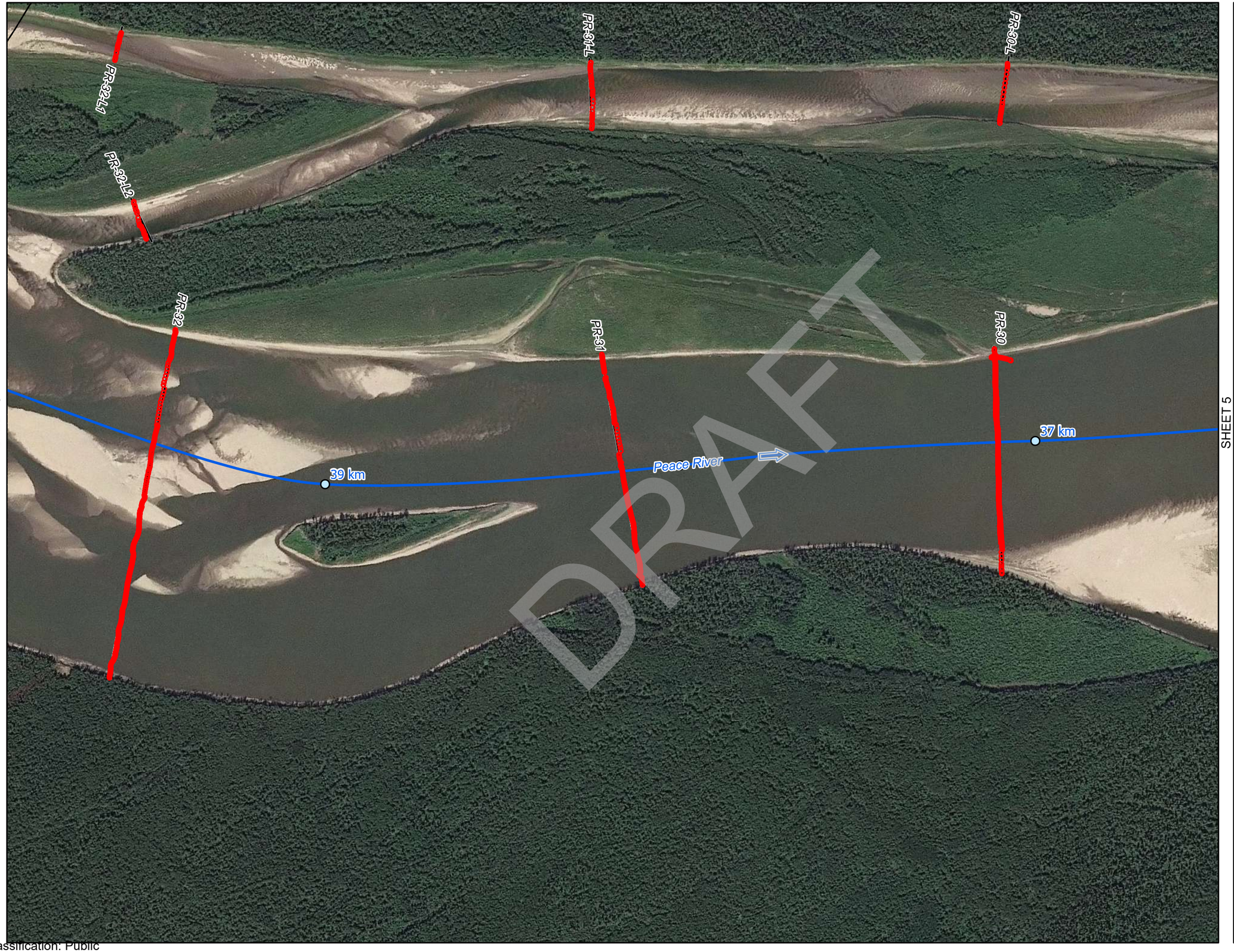
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 3 OF 25

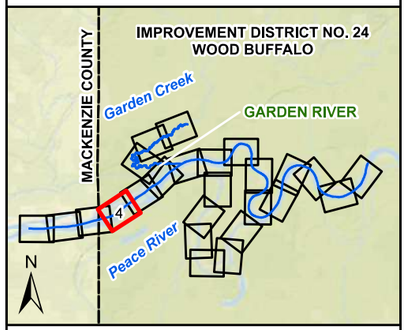
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- MAJOR HIGHWAY
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SCALE - 1:10,000

0 100 200 M

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

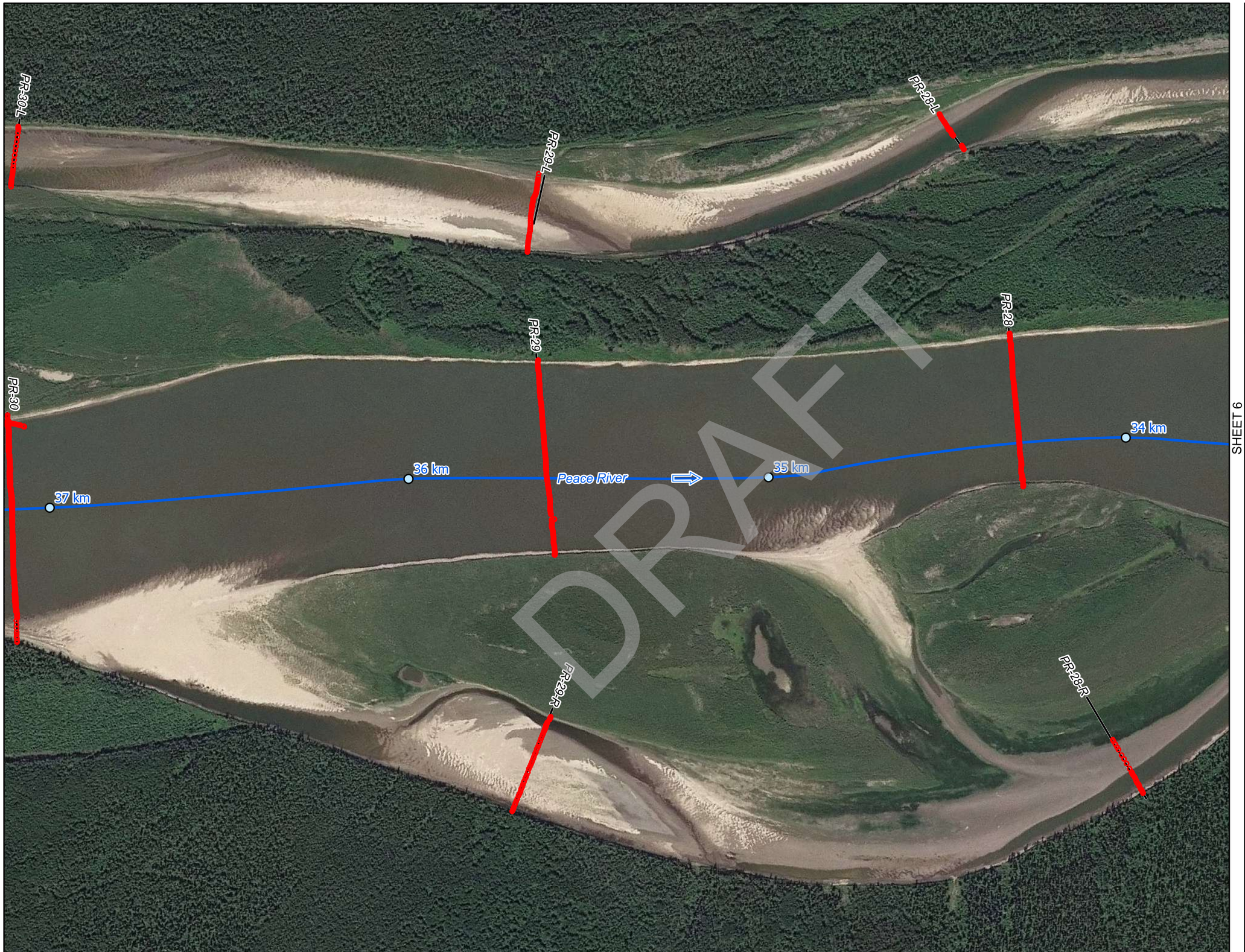
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 4 OF 25

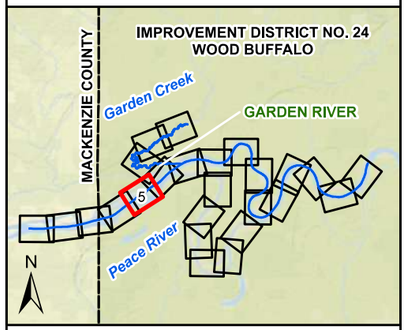
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Classification: Public



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- MAJOR HIGHWAY
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
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GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 5 OF 25

JY: P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study+File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

Classification: Public

SHEET 25

SHEET 5

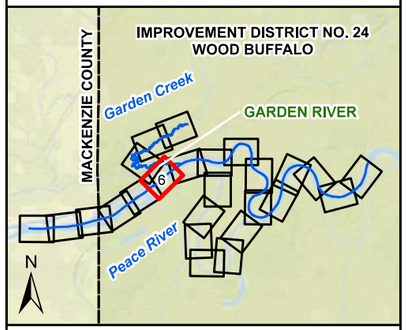
SHEET 7

PR-28-L
PR-27-L
PR-26-L
PR-28
PR-27
PR-26
PR-25
PR-28-R
GC-14
GC-13
GC-12
GC-11
GC-10
GC-09
GC-08
GC-07
GC-06
GC-05
GC-04
GC-03
Garden Creek
UNNAMED BRIDGE
1 km
34 km
33 km
32 km
Peace River

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- MAJOR HIGHWAY
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- CONTROL POINT
- ICE SCAR
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SCALE - 1:10,000

0 100 200 M

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
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Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 6 OF 25

J:\Y_P_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\05_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

Classification: Public

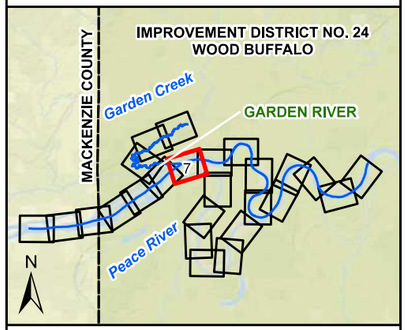


SHEET 6

SHEET 8

Alberta Canada

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

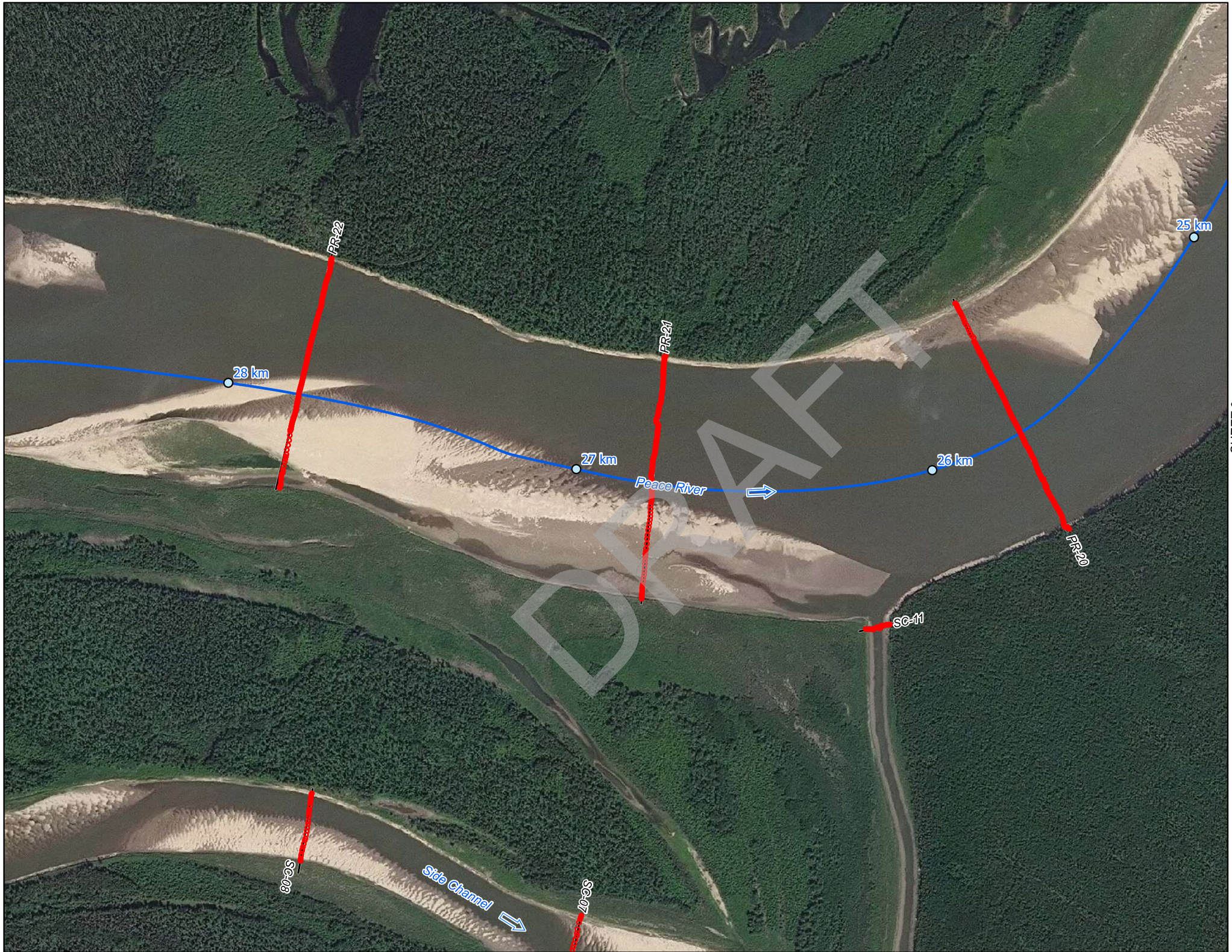
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Classification: Public

SHEET 7

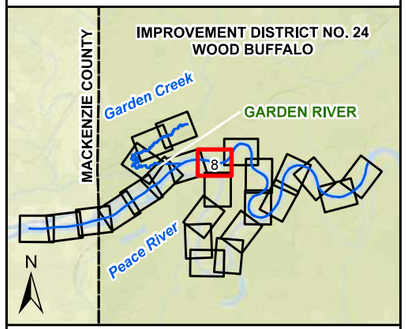
SHEET 9



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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

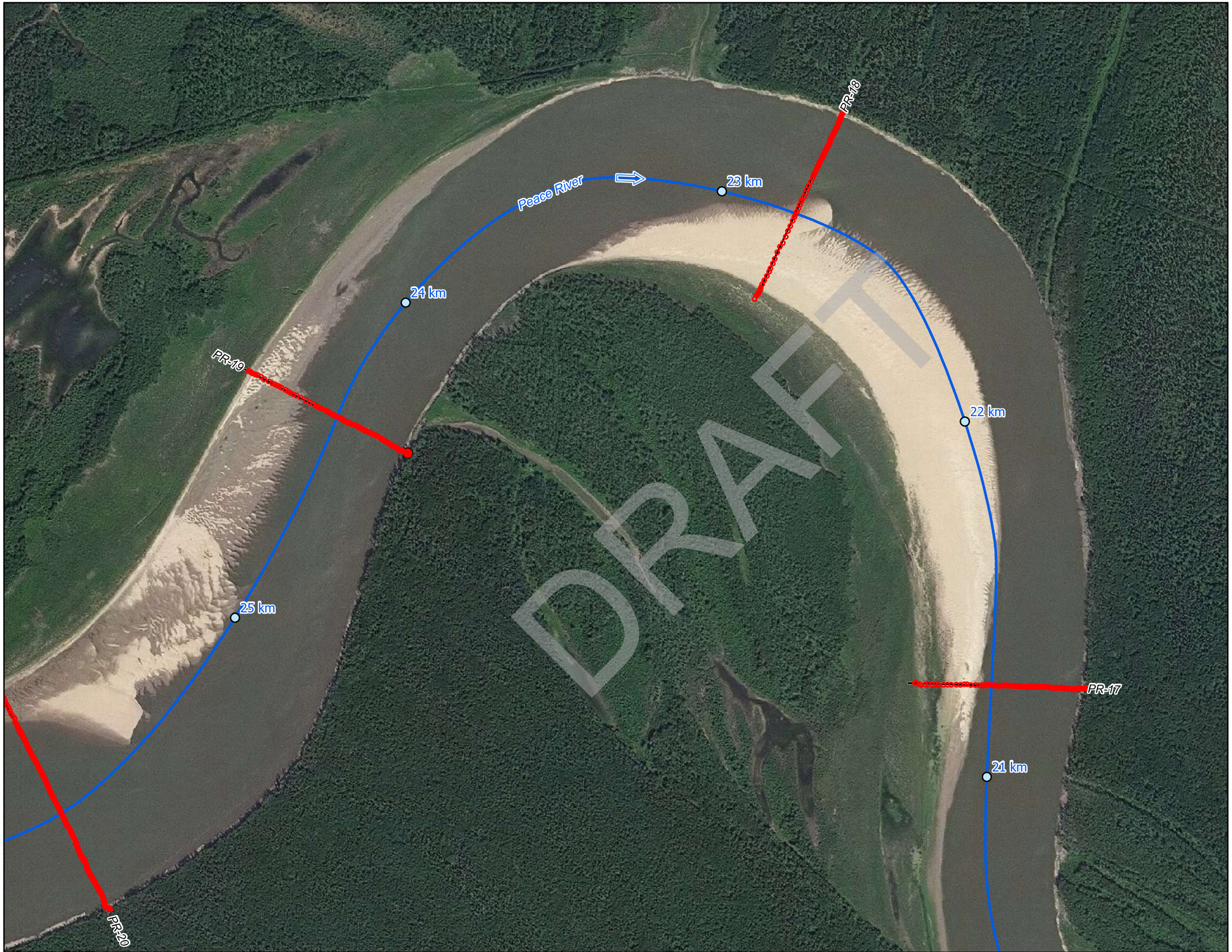
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 8 OF 25

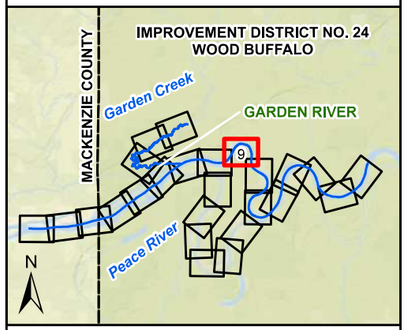
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Classification: Public



Alberta Canada

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- MAJOR HIGHWAY
- LOCAL ROAD
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- FLOW DIRECTION
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- DEBRIS PILE

SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

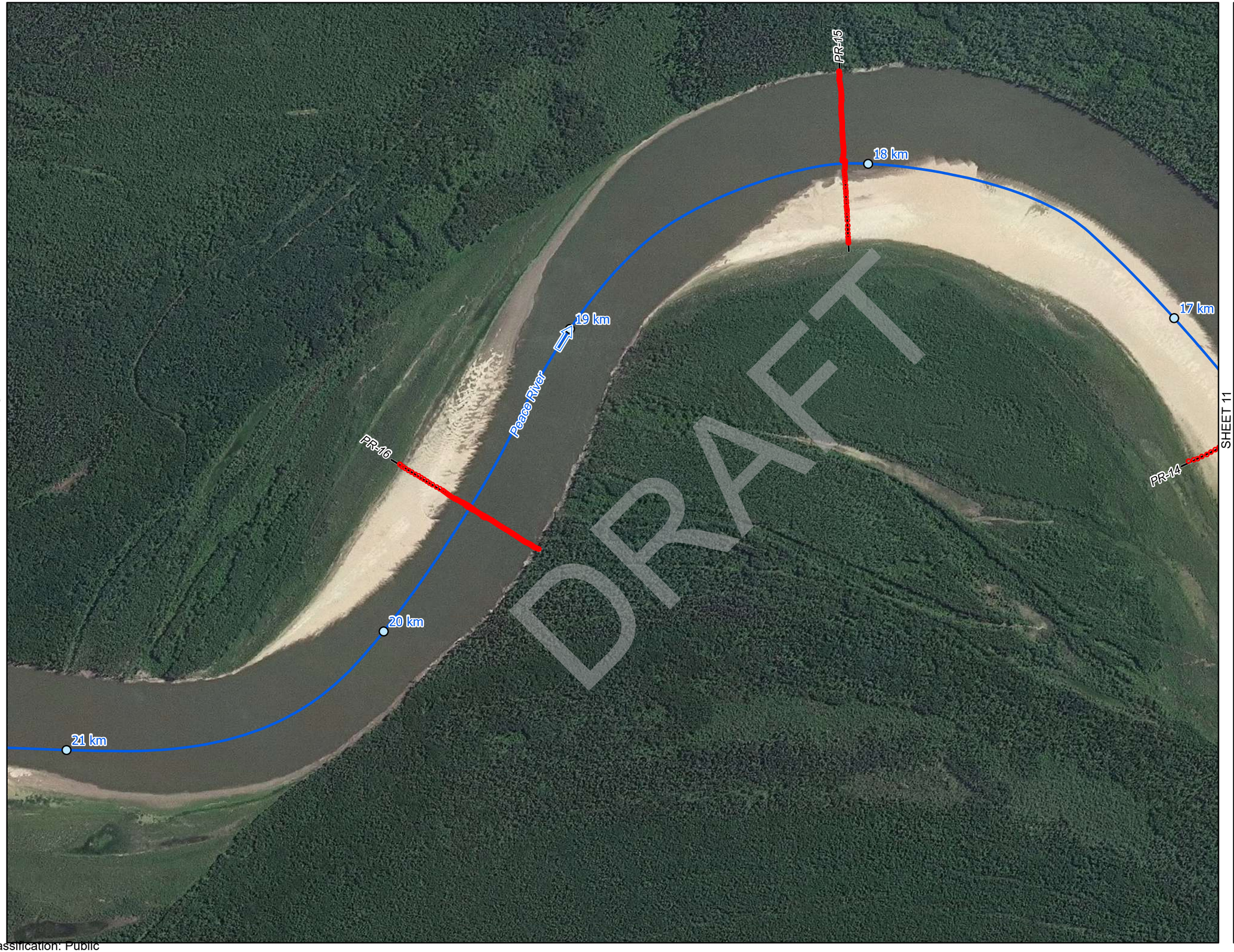
SURVEY OVERVIEW

SHEET 9 OF 25

SHEET 8

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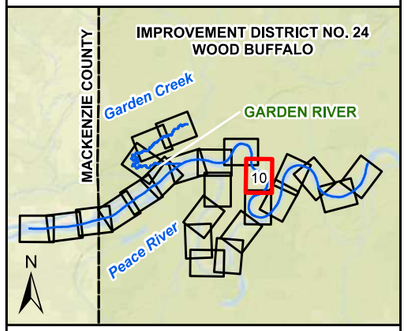
SHEET 9



SHEET 11

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- COUNTY DISTRICT
- SURVEY CROSS SECTION
- SURVEY POINT
- CONTROL POINT
- ICE SCAR
- DEBRIS PILE

SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

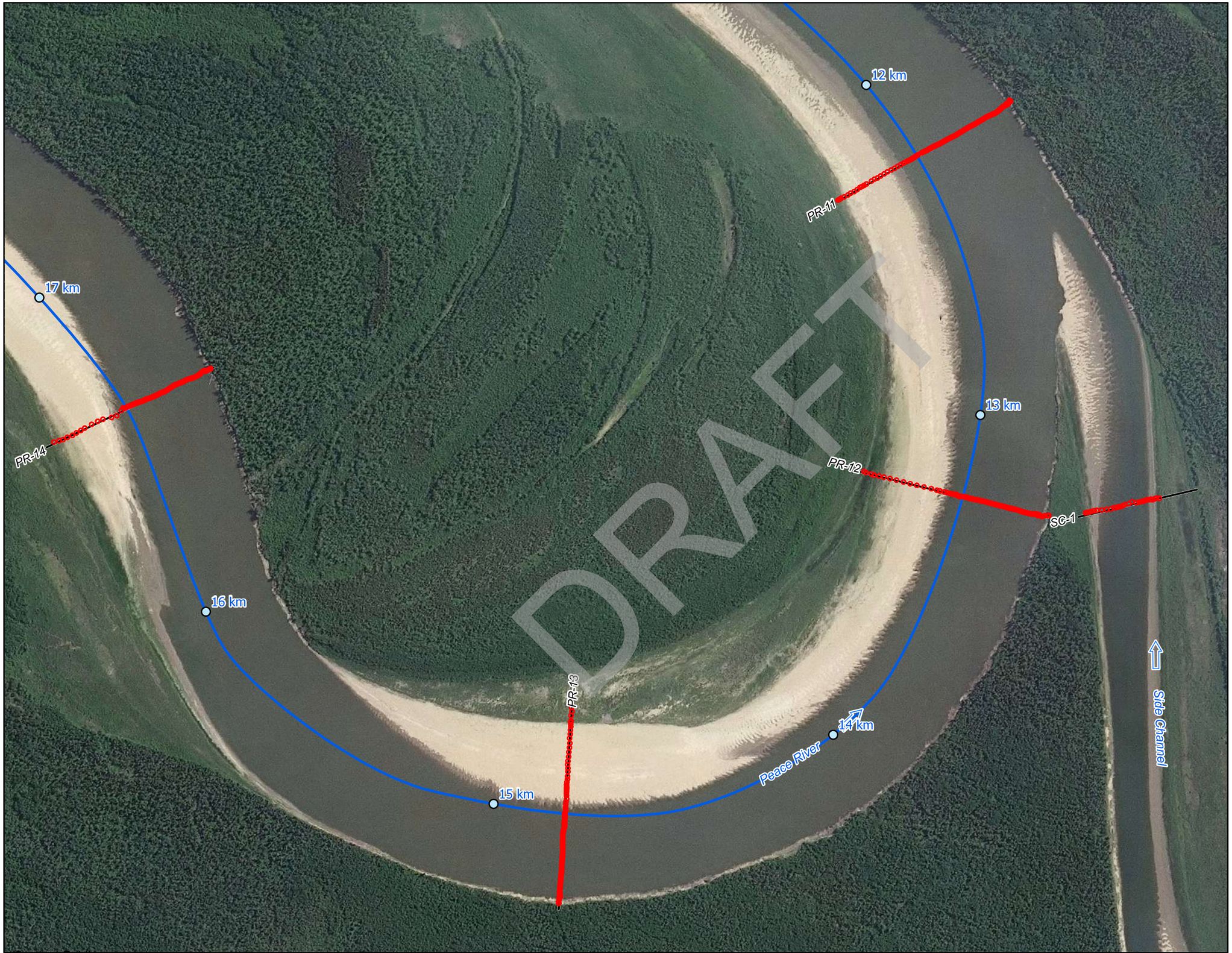
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 10 OF 25

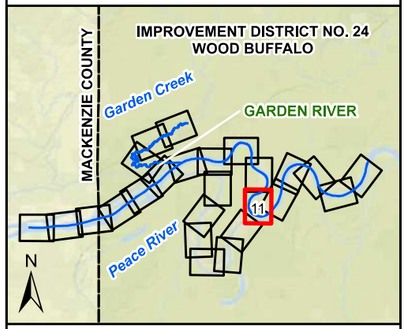
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SCALE - 1:10,000

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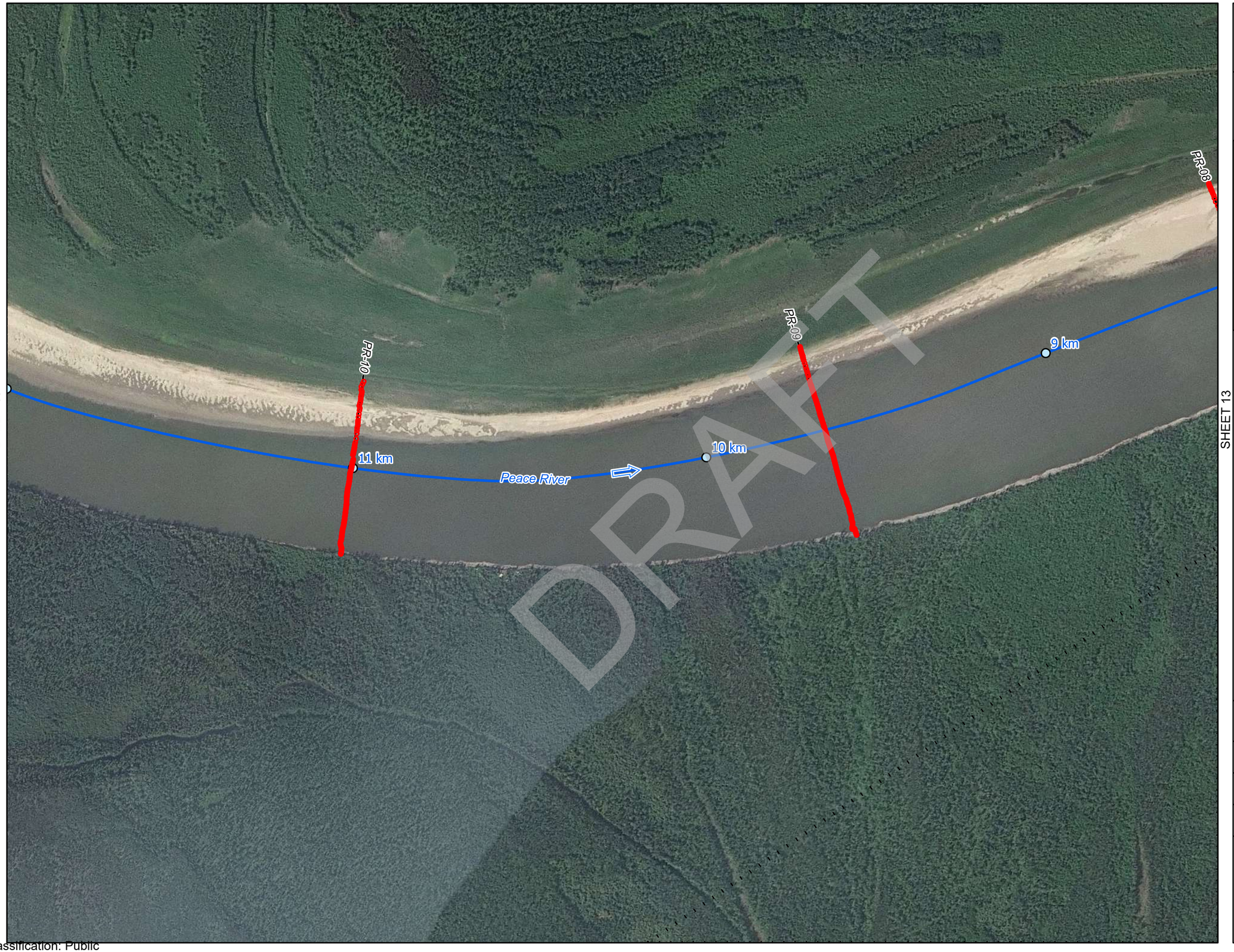
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 11 OF 25

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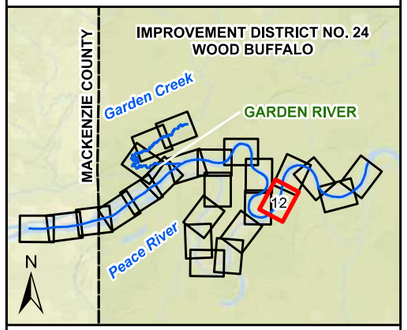
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SCALE - 1:10,000

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Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
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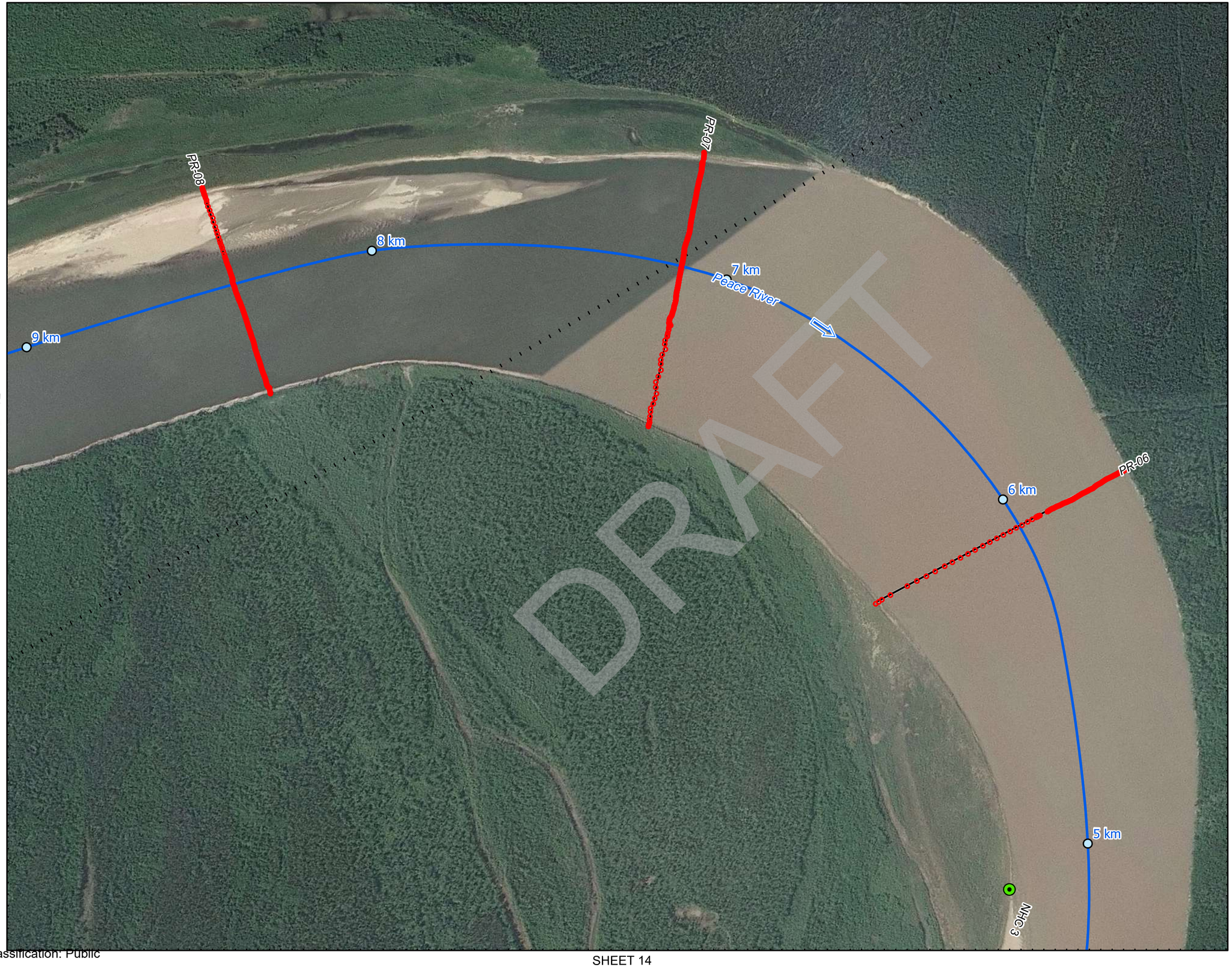
GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 12 OF 25

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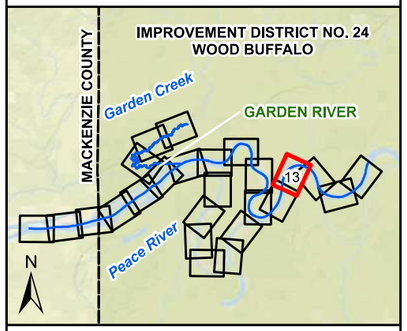
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SHEET 12

Alberta Canada

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

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Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 13 OF 25

JY: P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

SHEET 13

SHEET 15

PR-05

PR-04

4 km

5 km

3 km

2 km

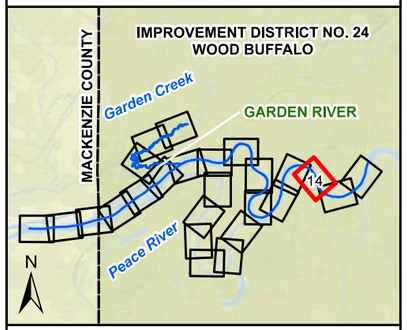
NHC 3

Peace River

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- MAJOR HIGHWAY
- LOCAL ROAD
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SCALE - 1:10,000

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Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 14 OF 25

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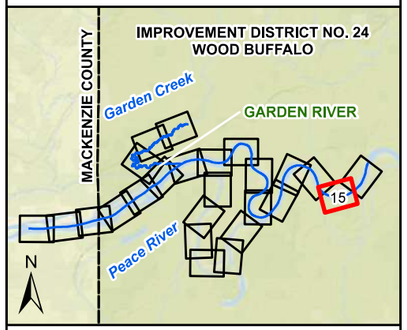
SHEET 14



SHEET 16

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 15 OF 25

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JY: P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

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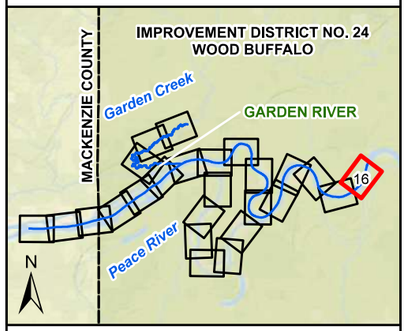
SHEET 15



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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

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Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 16 OF 25

JY: P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

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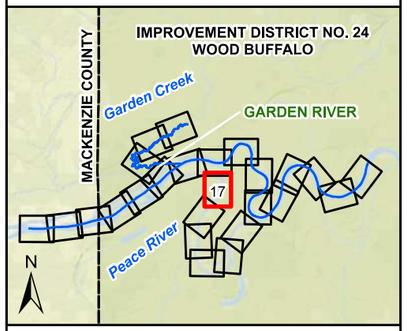
SHEET 8



SHEET 18

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 17 OF 25

JY, P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

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SHEET 17

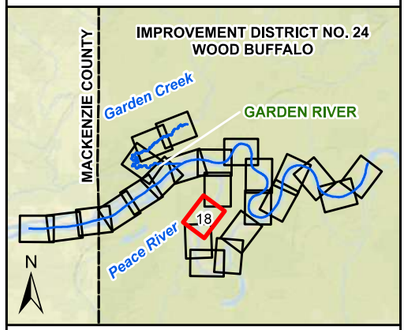


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SHEET 19

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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SCALE - 1:10,000

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Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

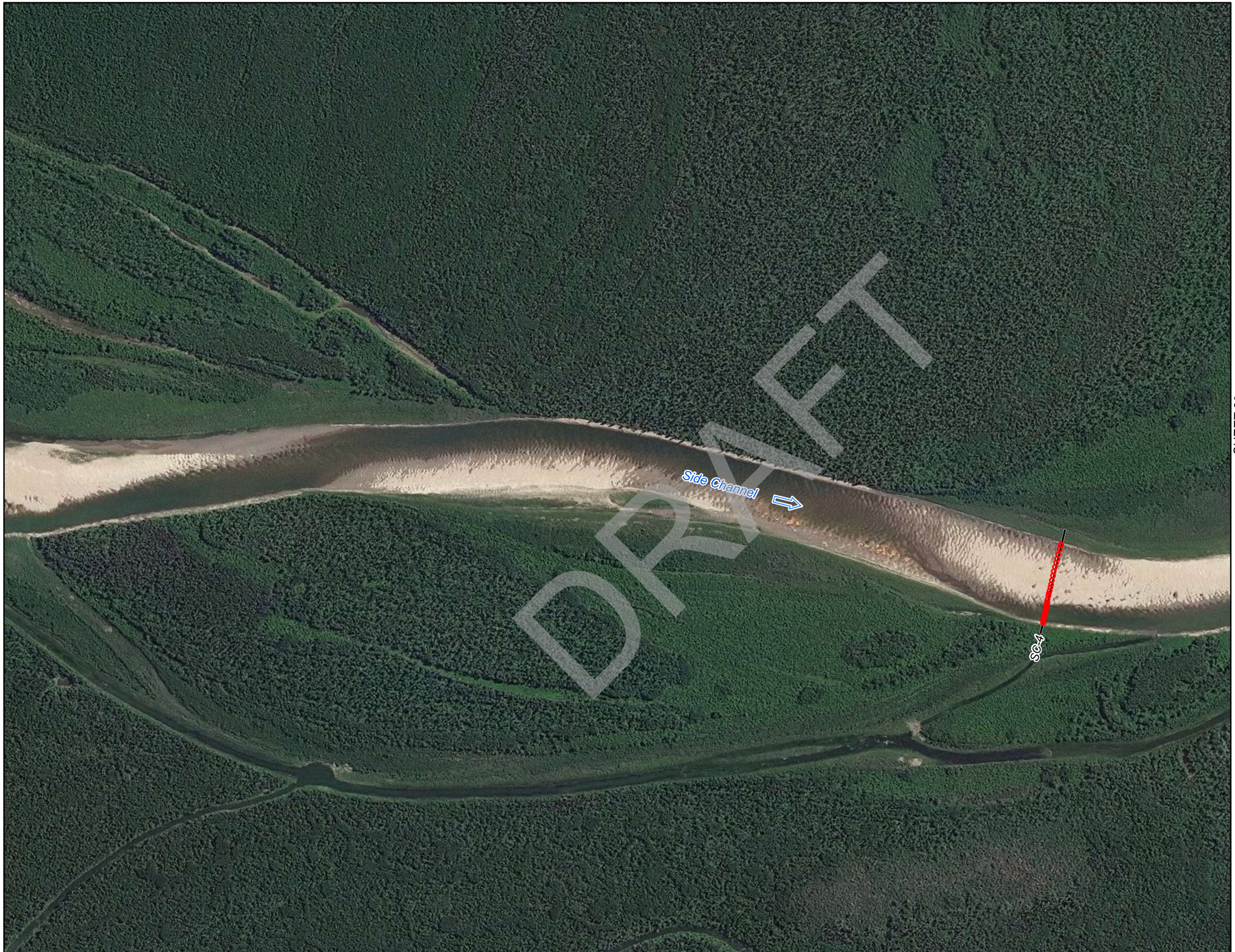
SURVEY OVERVIEW

SHEET 18 OF 25

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SHEET 18

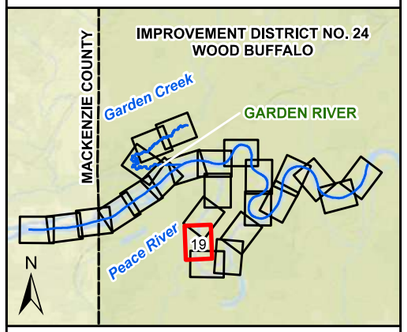


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SHEET 20

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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- SURVEY POINT
- CONTROL POINT
- ICE SCAR
- DEBRIS PILE

SCALE - 1:10,000

0 100 200 M

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Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 19 OF 25

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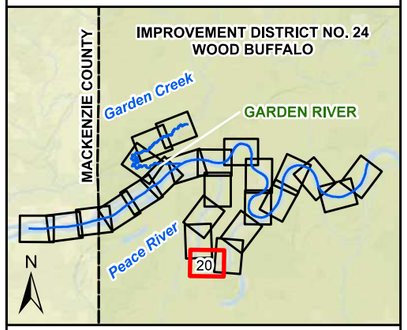
Classification: Public



SHEET 21

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- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
- 1 KM RIVER STATION
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- CONTROL POINT
- ICE SCAR
- DEBRIS PILE

SCALE - 1:10,000
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Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 20 OF 25

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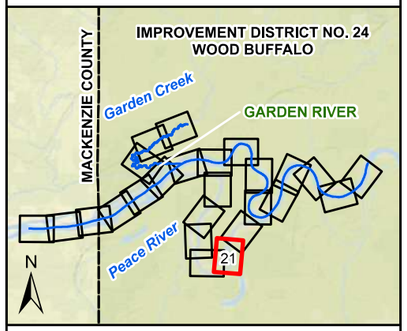
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SHEET 22

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 21 OF 25

JY, P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\05_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

Classification: Public

SHEET 21

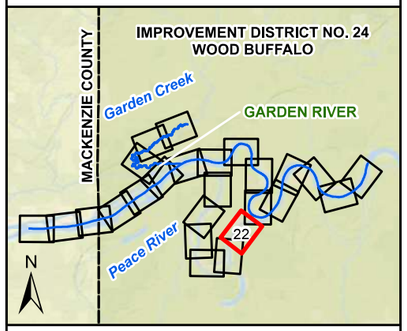


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SHEET 11

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SCALE - 1:10,000

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Coordinate System: NAD 1983 CSRS 3TM 114;
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Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 22 OF 25

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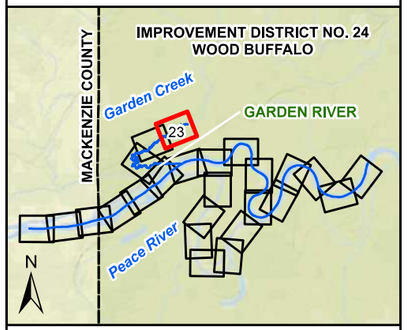
Classification: Public

SHEET 24



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- LOCAL ROAD
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- 1 KM RIVER STATION
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SCALE - 1:10,000

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 23 OF 25

J:\Y_P_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

Classification: Public

SHEET 25

SHEET 23

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NHC 6

NHC 5

12 km

13 km

14 km

15 km

16 km

17 km

GC-41

GC-42

GC-43

GC-44

GC-45

GC-46

GC-47

GC-48

GC-49

GC-50

GC-51

GC-52

GC-53

GC-54

GC-55

GC-56

Garden Creek

Highway 58

Alberta

Canada

nhc

IMPROVEMENT DISTRICT NO. 24
WOOD BUFFALO

MACKENZIE COUNTY

Garden Creek

GARDEN RIVER

24

Peace River

N

- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
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- FLOW DIRECTION
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SCALE - 1:10,000

0 100 200 M

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Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 24 OF 25

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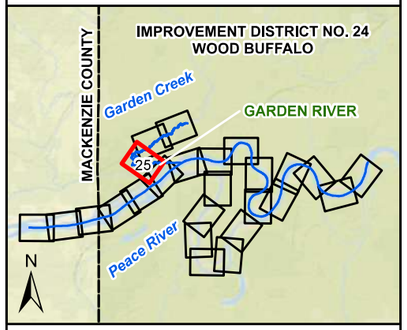
Classification: Public



SHEET 6

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nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- STUDY LIMITS
- RIVER CENTRE LINE
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SCALE - 1:10,000

0 100 200 M

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/KE	RBA

Job Number	Date
1009251	15-APR-2026

GARDEN RIVER FLOOD STUDY

SURVEY OVERVIEW

SHEET 25 OF 25

JY, P:_Projects (Active)\1009251 Garden River Flood Study\1000 Study-File_GRFS\95_GIS\100 Survey\1009251_Survey_Overview_Maps_STUDY_FILE.aprx

Classification: Public

APPENDIX C

HYDRAULIC STRUCTURES

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Classification: Public

Bridge Description

Name:	Garden River Bridge	**Bridge File No.:**	79537
River:	Garden Creek	**River Station (m):**	1,006

Geometry

Span (m):	32.30	**Minimum High Chord (m):**	234.69
Width (m):	5.75	**Minimum Low Chord (m):**	233.90
Pier Type:	Steel	**No. of Piers:**	2
Pier Shape:	Tapered	**Pier Width (m):**	1.35

Photo(s)

Looking downstream on upstream side of the of bridge



Looking upstream on downstream side of bridge



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Bridge Description

Name:	Highway 58 Bridge	**Bridge File No.:**	79536
River:	Garden Creek	**River Station (m):**	10,501

Geometry

Span (m):	37.90	**Minimum High Chord (m):**	235.54
Width (m):	9.95	**Minimum Low Chord (m):**	236.04
Pier Type:	Steel Pile	**No. of Piers:**	2
Pier Shape:	Circular	**Pier Width (m):**	0.30

Photo(s)

Looking downstream on upstream side of the of bridge



Looking upstream on downstream side of bridge



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Classification: Public

APPENDIX D

REACH REPRESENTATIVE PHOTOS

DRAFT

Classification: Public



1. Looking downstream along Garden Creek from GC-51.



2. Looking upstream along Garden Creek from GC-32.



3. Looking upstream along Garden Creek from GC-14.



4. Looking upstream along Garden Creek from the Garden River bridge.



5. Looking downstream along Garden Creek from GC-03.



6. Looking downstream at confluence of Garden Creek and Peace River.

DRAFT

Notes:

Photos taken by NHC during survey from October 2 to 4, 2024

GARDEN RIVER FLOOD STUDY

REACH REPRESENTATIVE PHOTOS: GARDEN CREEK

Job: 1009251	*Date: Apr-2026*	*D - 1*

Classification: Public



7. Looking downstream at split of Peace River main channel and left side channel from PR-33.



8. Looking downstream along left side channel of Peace River near PR-32-L1.



9. Looking upstream along left side channel of Peace River from PR-29-L.



10. Looking upstream along left side channel of Peace River at PR-27-L.



11. Overhead view looking upstream at Peace River main and left side channels from PR-26-L.



12. Looking upstream at the confluence of the main and left side channel of the Peace River from PR-24.

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13. Looking downstream at Big Island which splits the Peace River from PR-26.



14. Looking downstream from PR-20 at SC-11 at the secondary entrance to side channel.



15. Looking downstream along Side Channel from SC-6.



16. Looking upstream along side channel of Peace River from SX-4.



17. Looking downstream at side channel of Peace River from SC-4.



18. Looking downstream at confluence of side channel and Peace River from SC-1.

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Alberta Canada nhc

GARDEN RIVER FLOOD STUDY

REACH REPRESENTATIVE PHOTOS: PEACE RIVER SIDE-CHANNEL

Job: 1009251	*Date: Apr-2026*	*D - 3*

Classification: Public



19. Looking downstream along Peace River from PR-37 (at the upstream study boundary).



20. Looking downstream at split of Peace River into main and left side channels from PR-33.



21. Looking downstream along Peace River from PR-30.



22. Looking upstream on Peace River from PR-22.



23. Looking upstream on Peace River from PR-18.



24. Looking downstream along Peace River near PR-15.

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Classification: Public



25. Looking downstream along Peace River from PR-06.



26. Looking downstream along Peace River near PR-03.



27. Looking downstream along Peace River near PR-01 (the downstream study boundary.

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Classification: Public

APPENDIX E

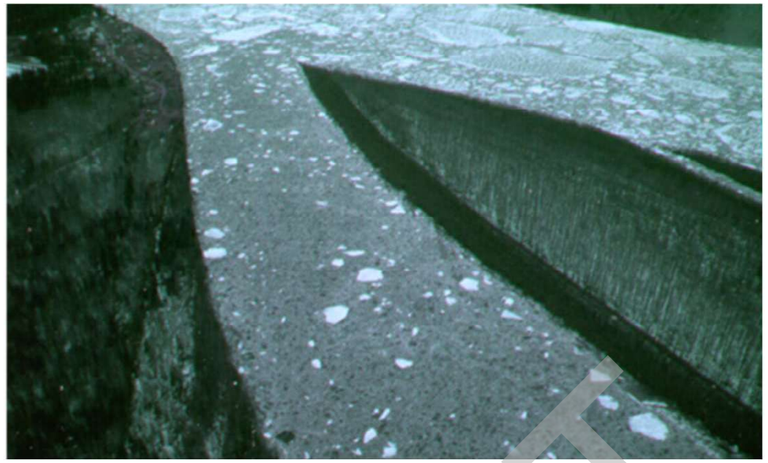
FLOOD HISTORY PHOTOGRAPHS

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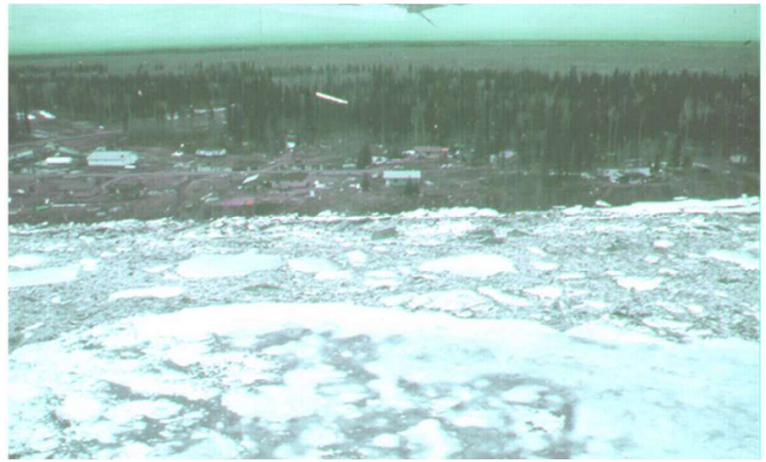
Classification: Public



1. 1996 ice jam flood – Flooding along the Peace River at Garden River, looking across the river at Garden River from the right bank near PR-26.



2. 1996 ice jam flood – Flooding along the Peace at Garden River, looking downstream along the side channel upstream of Garden River. The community of Garden River is located at the top left of photo.



3. 1996 ice jam flood – Flood along the Peace River at Garden River, looking at the community of Garden River along the left bank of the Peace River near PR-25.



4. 2018 ice jam flood – Flooding at the bridge within Garden River at GC-08 caused by backwater from an ice jam on Peace River.



5. 2018 ice jam flood – Looking at the ice jam on the Peace River near the old lagoon site on the left bank of the Peace River upstream of PR-23.



Ice Jam M at Garden River on Apr 30. Photo credit: Parks Canada.

6. 2020 ice jam flooding – Ice Jam flooding at Garden River.

Notes:

Photos 1 to 3 were taken on April 30, 1996, by Parks Canada.
Photos 4 and 5 were taken in spring of 2018 by Luke Kostyk.
Photos 6 was taken on April 30, 2020, by Parks Canada

GARDEN RIVER FLOOD STUDY

HISTORIC FLOOD PHOTOS

Job: 1009251	Date: Apr-2026	E - 1

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Classification: Public



7. 2020 open water flood – Open water flooding near Garden River.



8. 2020 open water flood – Open water flooding near Garden River.



9. Ice scar – tree scar along the right bank of the Peace River near PR-4.
(Photo 1 of 2)



10. Ice scar – tree scar along the right bank of the Peace River near PR-4.
Photo (2 of 2)



11. Ice scar – tree scar along the right bank of the Peace River near PR-19.



12. Ice scar – tree scar along Garden Creek upstream of GC-04
(Photo 1 of 2)

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Notes:

Photo 7 was taken on July 6, 2020, by Sentinel Satellite.
Photo 8 to 12 were taken by NHC personnel in October 2024 and May 2025.

GARDEN RIVER FLOOD STUDY

HISTORIC FLOOD, HIGHWATER MARK, AND ICE SCAR PHOTOS

Job: 1009251	Date: Apr-2026	E - 2

Classification: Public



13. Ice scar – tree scar along Garden Creek downstream of GC-04. (Photo 2 of 2)



14. Ice Scar – tree scar along the left bank at GC-03.



15. Ice Scar – tree scar along the right bank downstream of GC-03.

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Notes:

Photos 13 to 15 were taken by NHC personnel in October 2024.

GARDEN RIVER FLOOD STUDY

ICE SCAR PHOTOS

Job: 1009251	Date: Apr-2026	E - 3

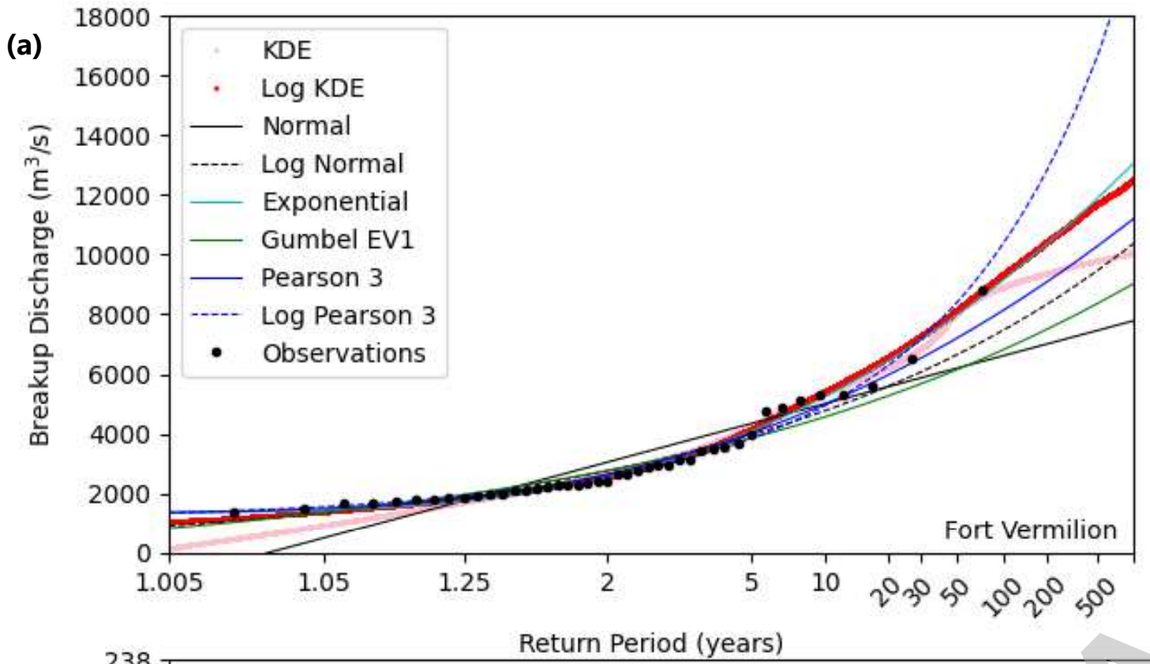
Classification: Public

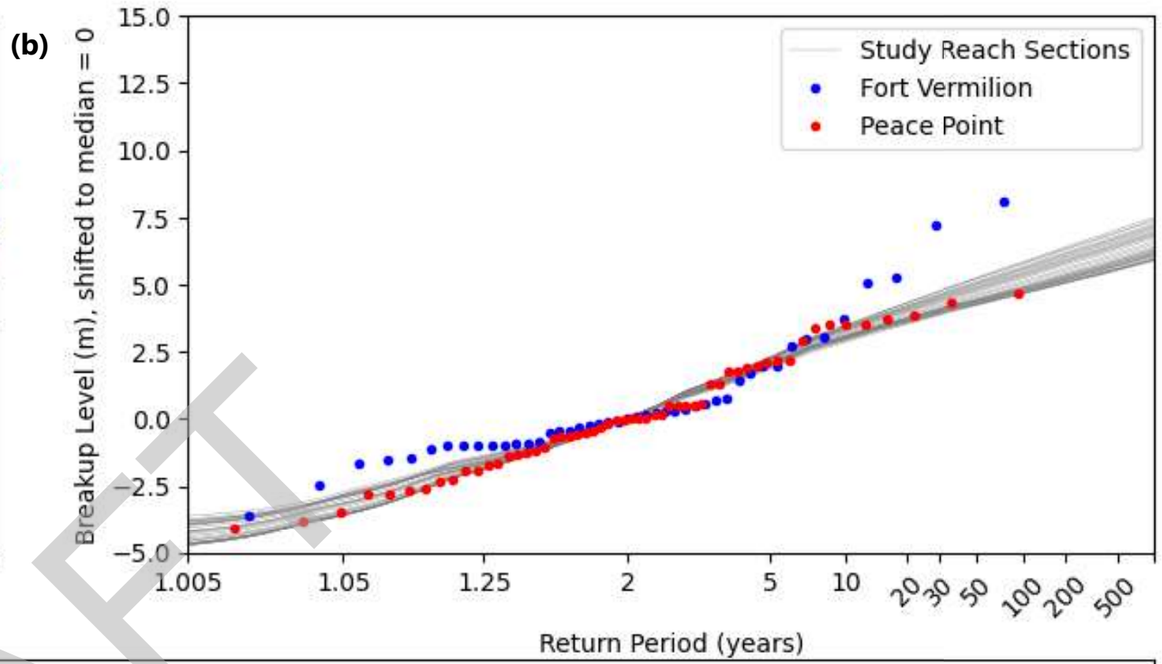
APPENDIX F

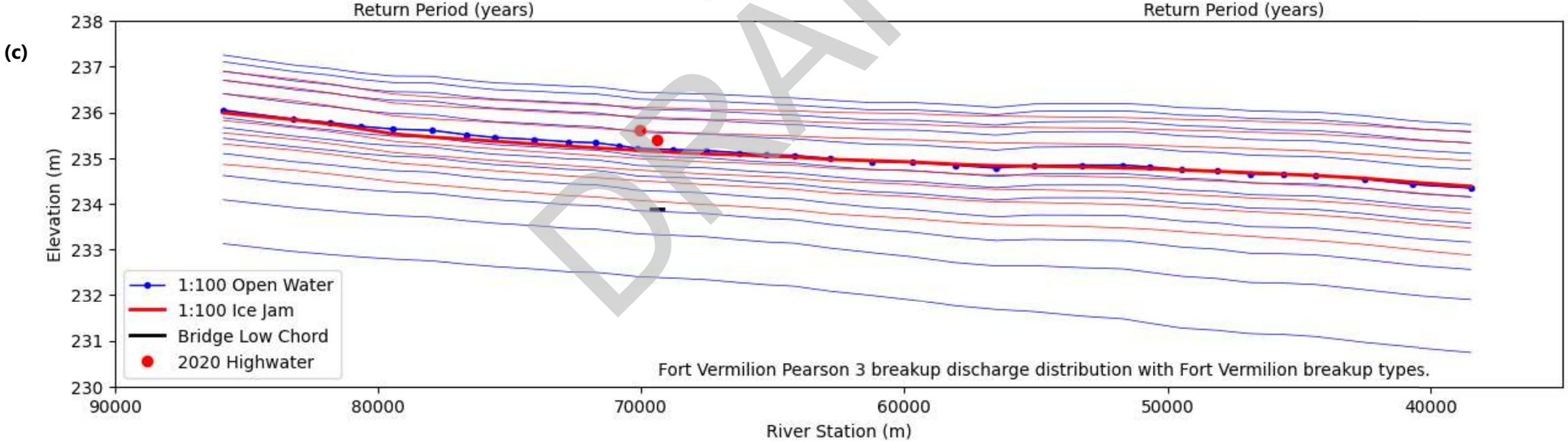
MONTE CARLO BREAKUP SCENARIOS

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Classification: Public







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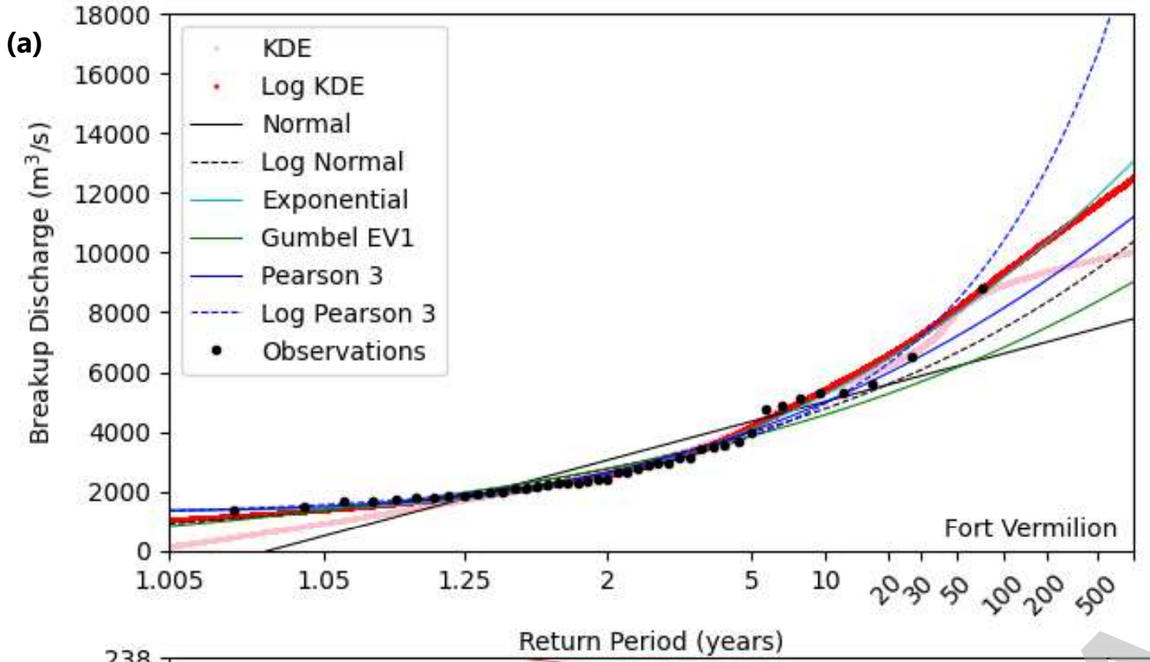
Notes: a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
b) Breakup level distributions are adjusted vertically to align the median to zero. Grey lines represent the family of breakup level distributions computed at all Peace River model sections.
c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

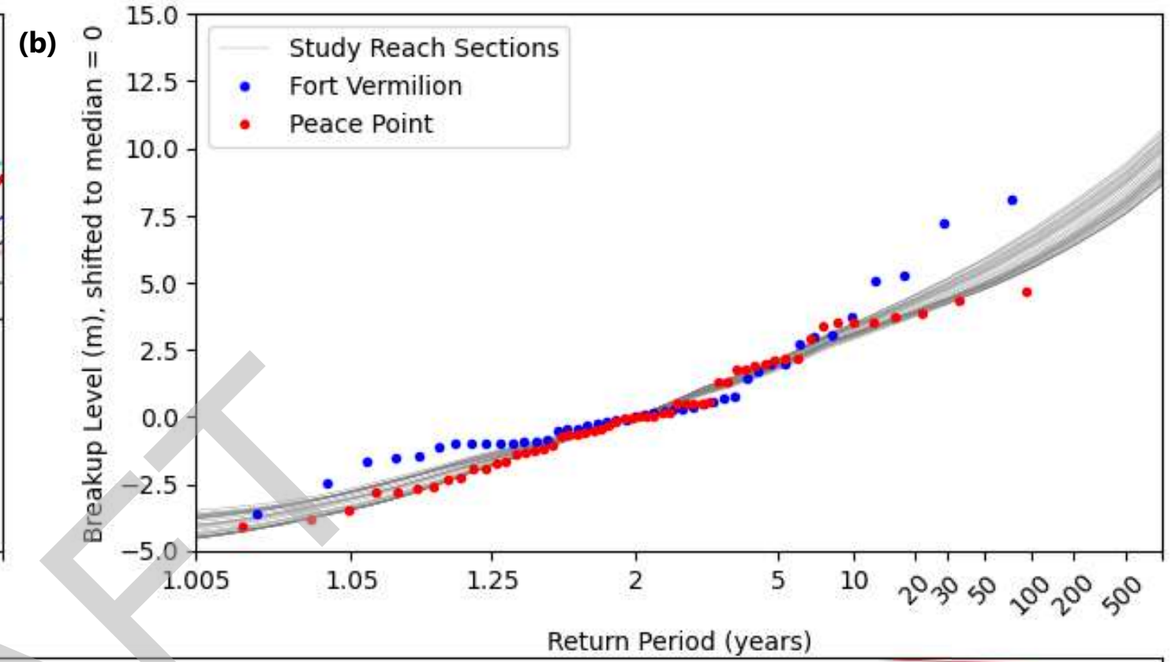
GARDEN RIVER FLOOD STUDY

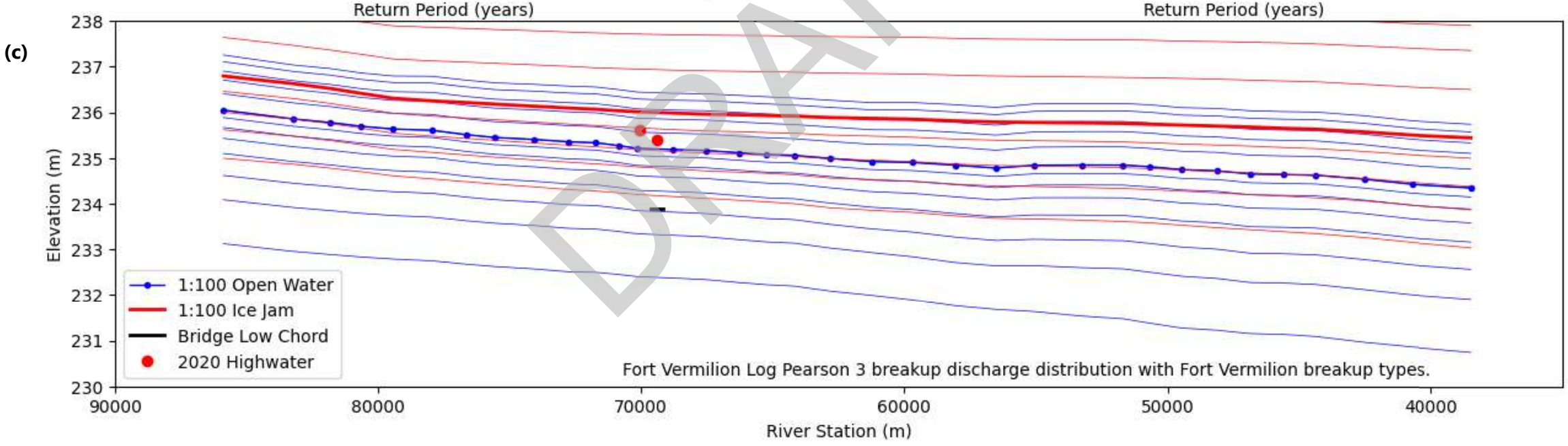
SCENARIO 1 MONTE CARLO RESULTS
FV Q_{P3} | $FV_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 1

Classification: Public







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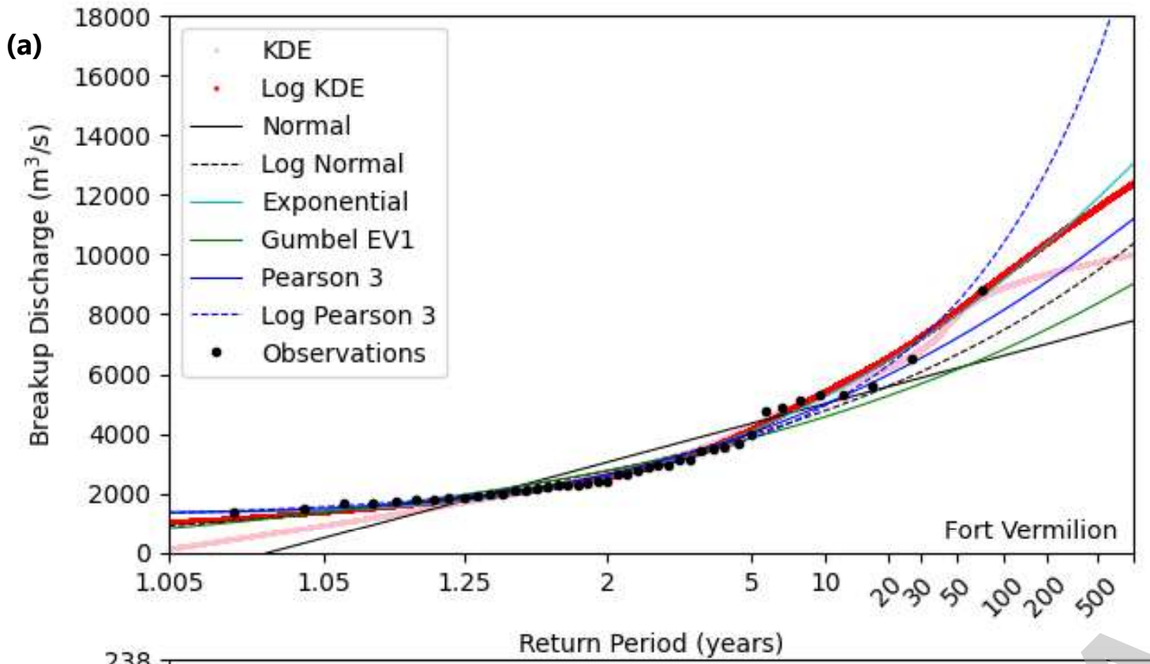
Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
b) Breakup level distributions are adjusted vertically to align the median to zero. Grey lines represent the family of breakup level distributions computed at all Peace River model sections.
c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

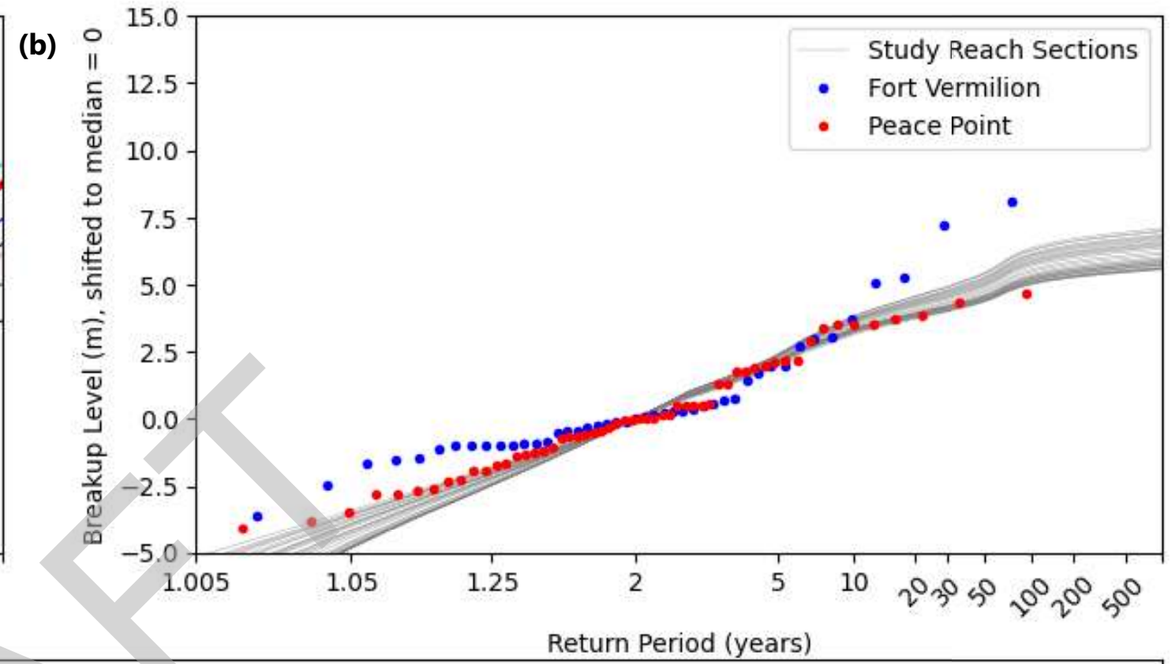
GARDEN RIVER FLOOD STUDY

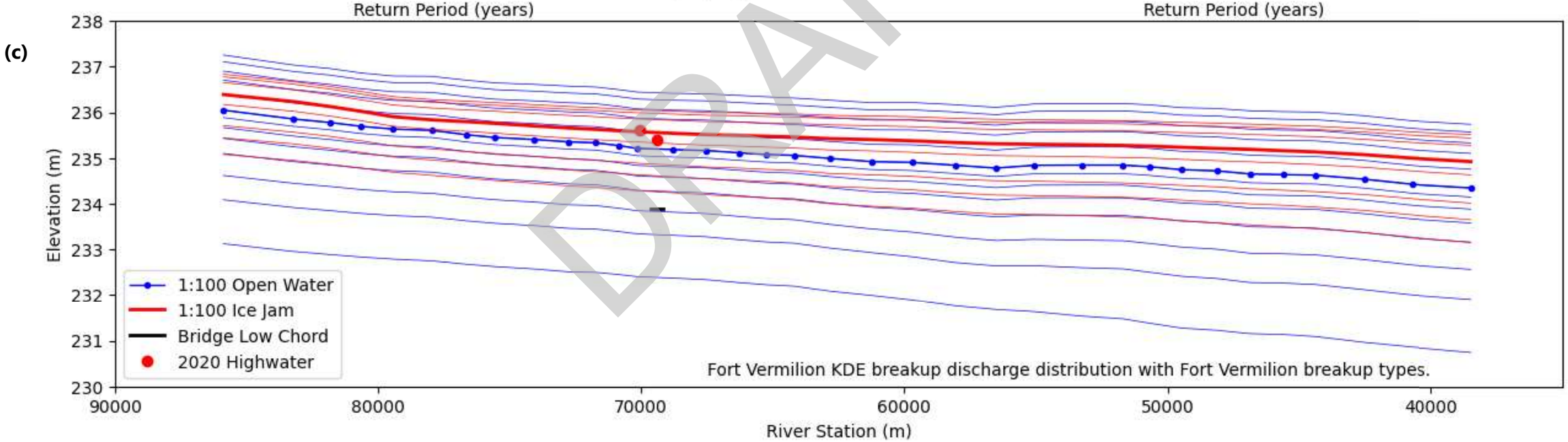
SCENARIO 2 MONTE CARLO RESULTS
FV Q_{LP3} | FV $_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 2

Classification: Public







DRAFT

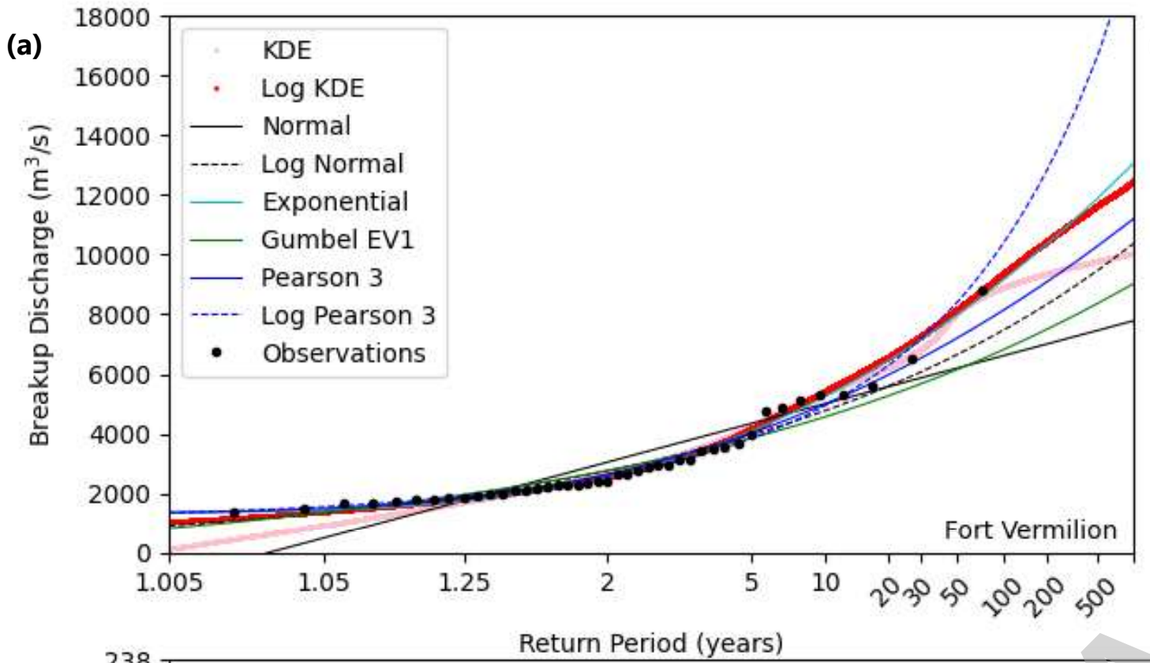
Notes: a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

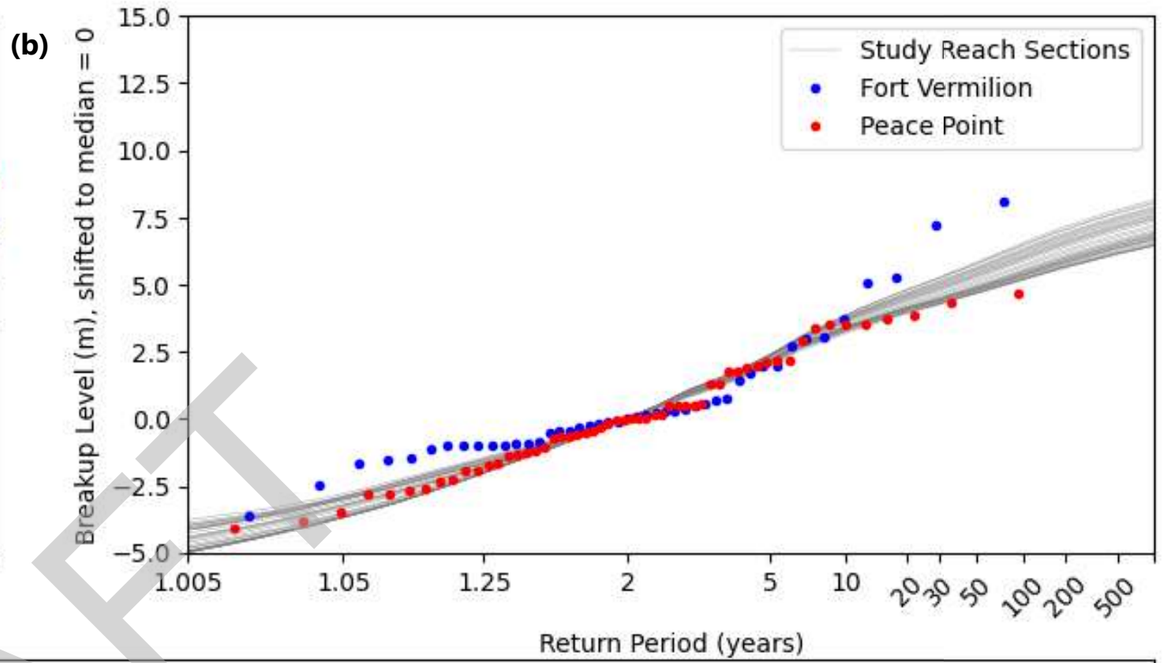
GARDEN RIVER FLOOD STUDY

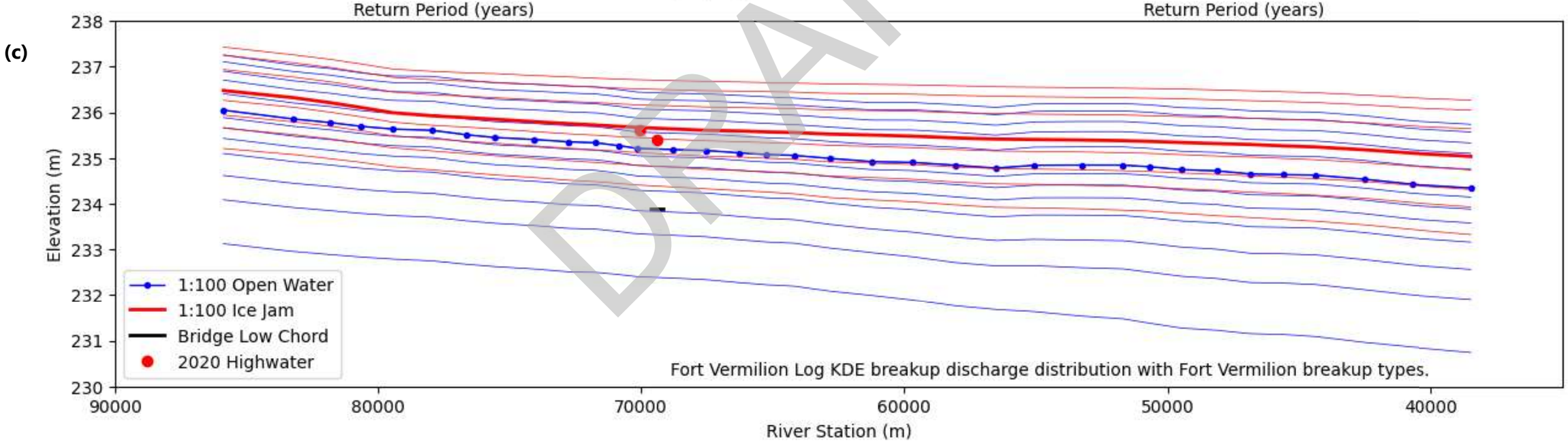
SCENARIO 3 MONTE CARLO RESULTS
FV Q_{KDE} | FV $_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 3

Classification: Public







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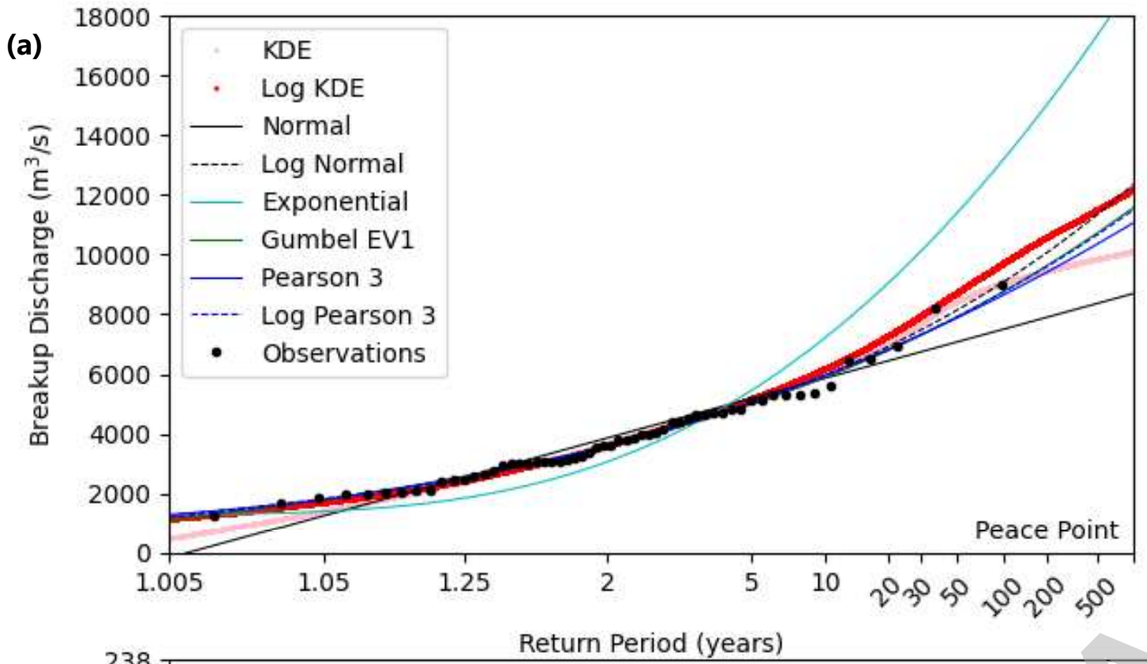
Notes: a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

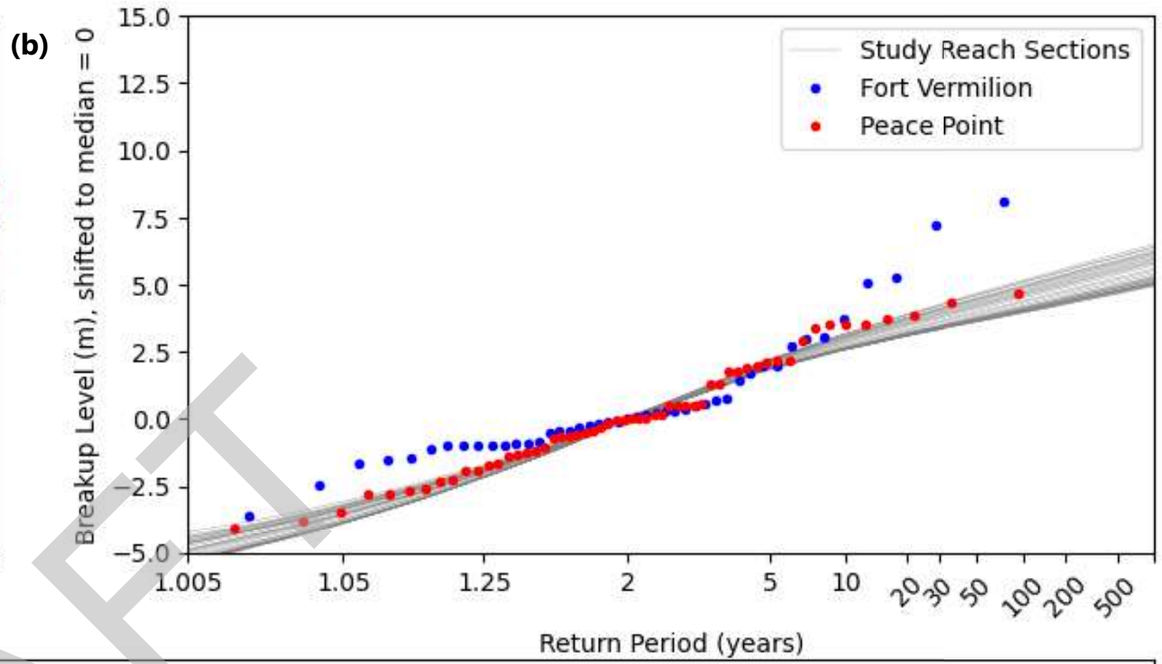
GARDEN RIVER FLOOD STUDY

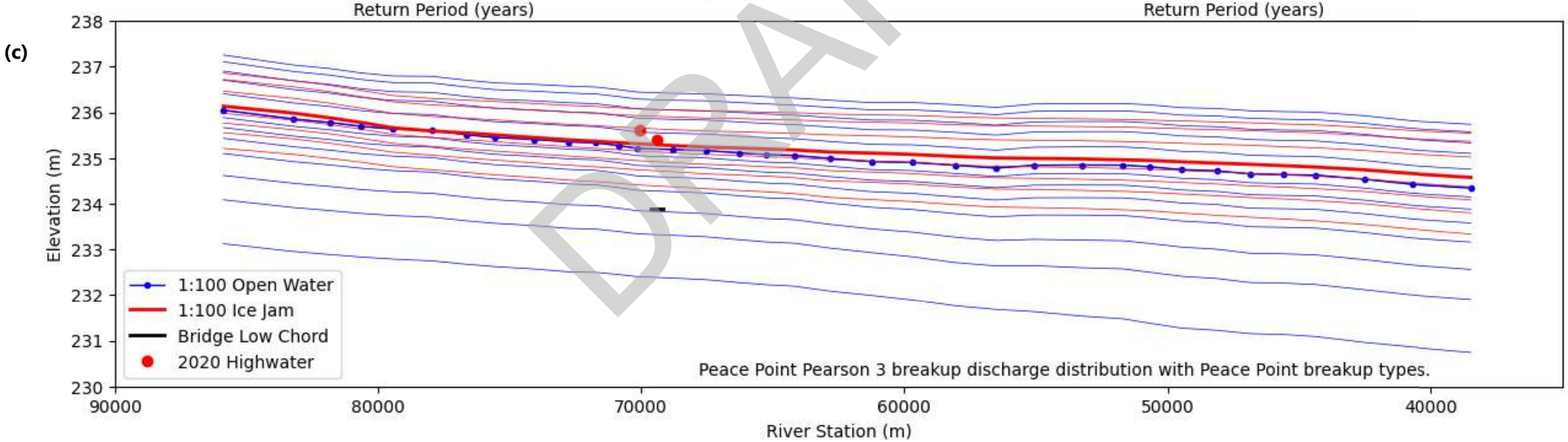
SCENARIO 4 MONTE CARLO RESULTS
FV $Q_{LOG\ KDE}$ | $FV_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 4

Classification: Public







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Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
b) Breakup level distributions are adjusted vertically to align the median to zero. Grey lines represent the family of breakup level distributions computed at all Peace River model sections.
c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

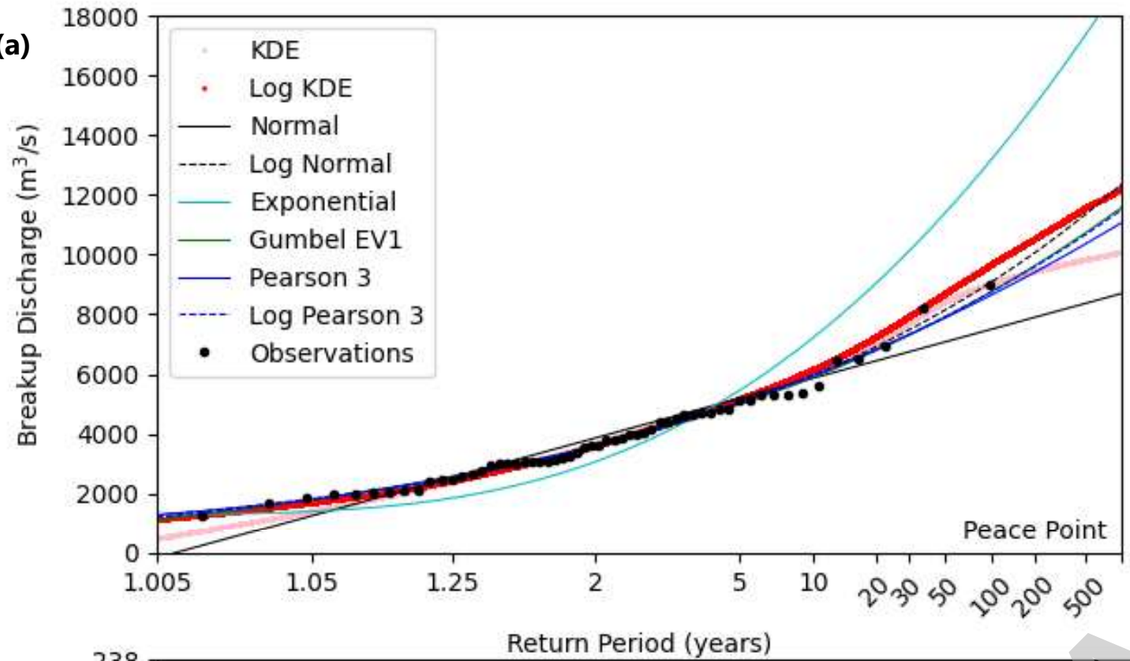
GARDEN RIVER FLOOD STUDY

SCENARIO 5 MONTE CARLO RESULTS
PP Q_{P3} | $PP_{ICE\ TYPES}$

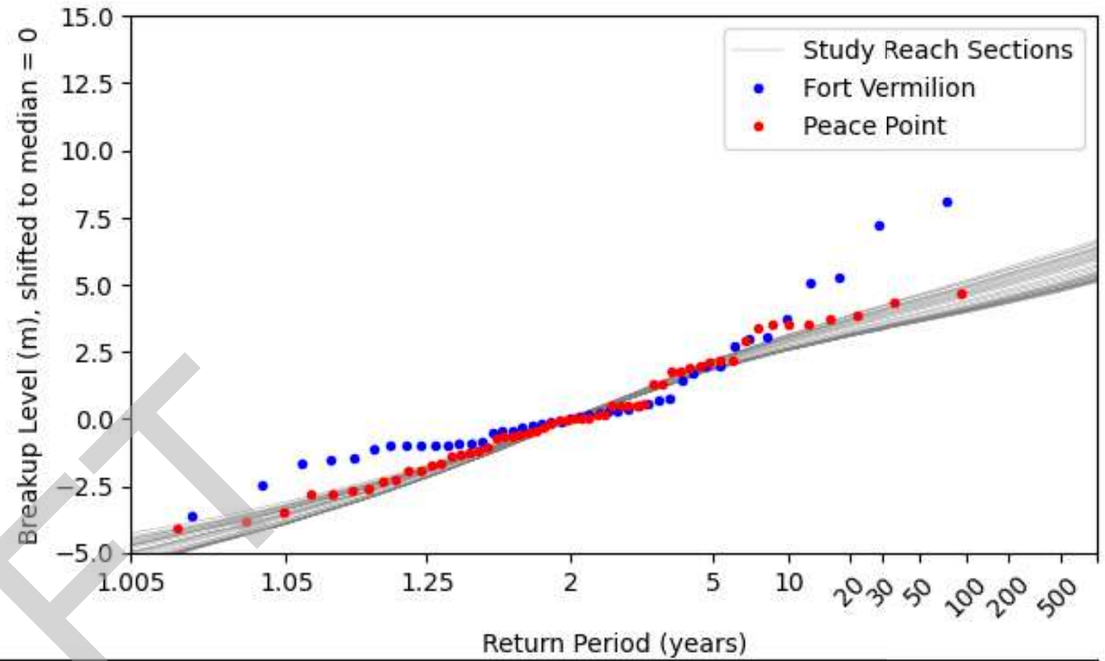
Job: 1009251	Date: Apr-2026	F - 5

Classification: Public

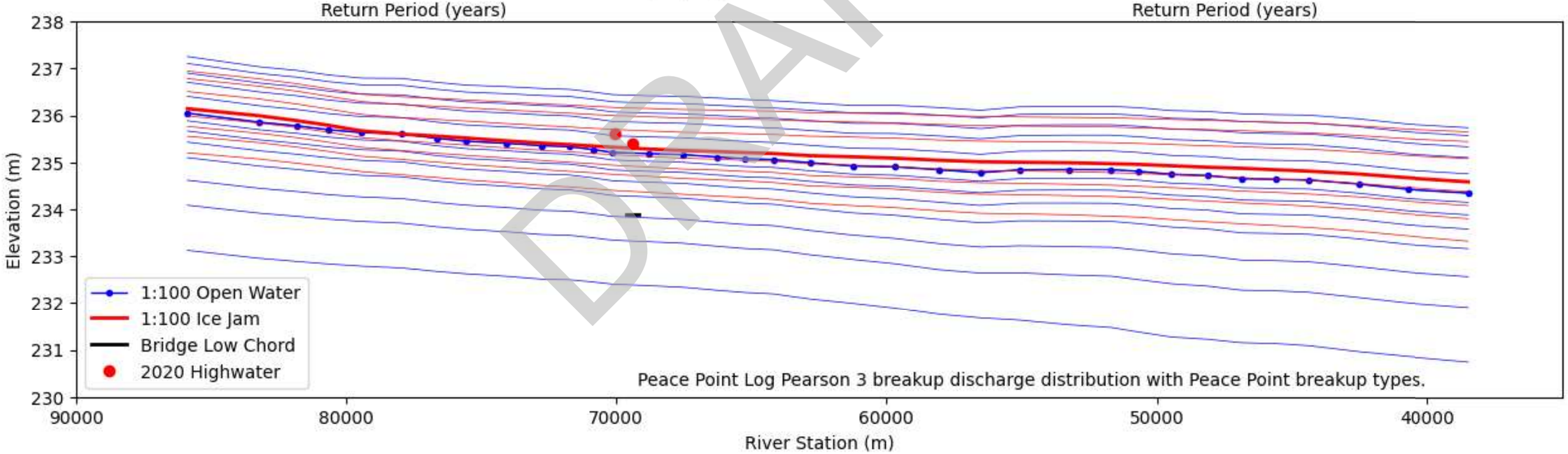
(a)



(b)



(c)



DRAFT

Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
b) Breakup level distributions are adjusted vertically to align the median to zero. Grey lines represent the family of breakup level distributions computed at all Peace River model sections.
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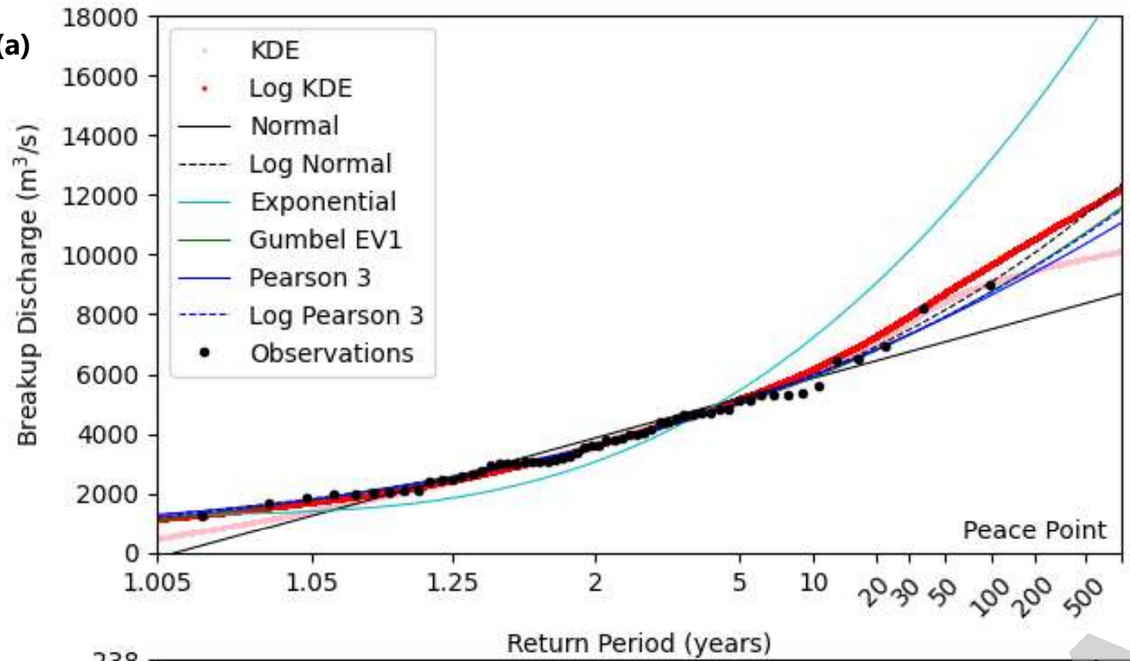
GARDEN RIVER FLOOD STUDY

SCENARIO 6 MONTE CARLO RESULTS
PP Q_{LP3} | $PP_{ICE\ TYPES}$

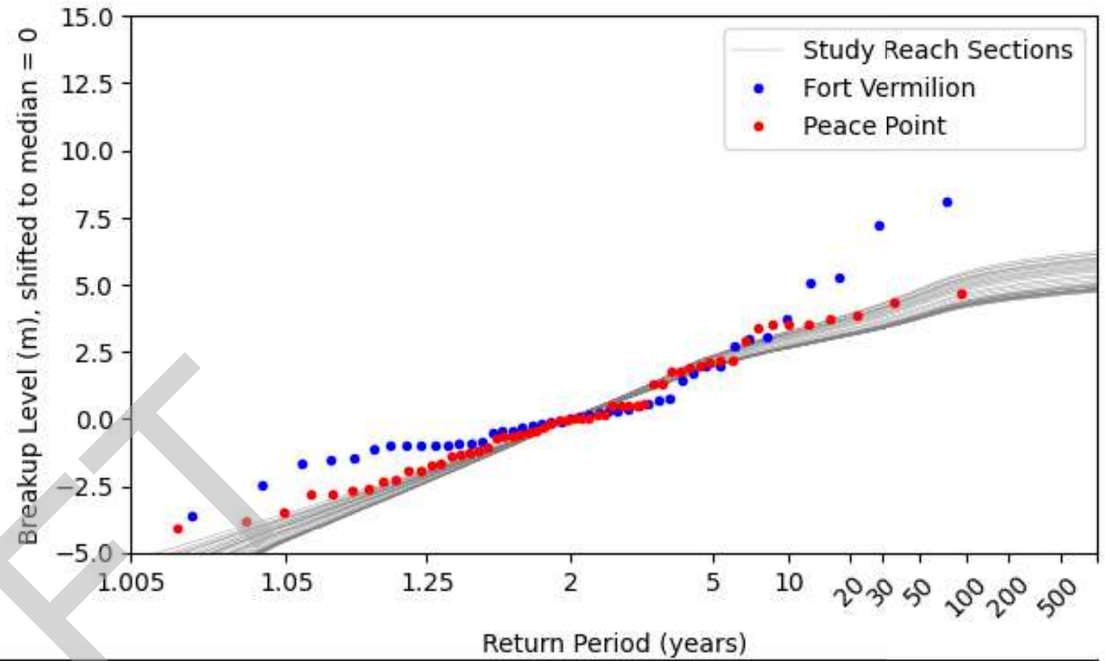
Job: 1009251	Date: Apr-2026	F - 6

Classification: Public

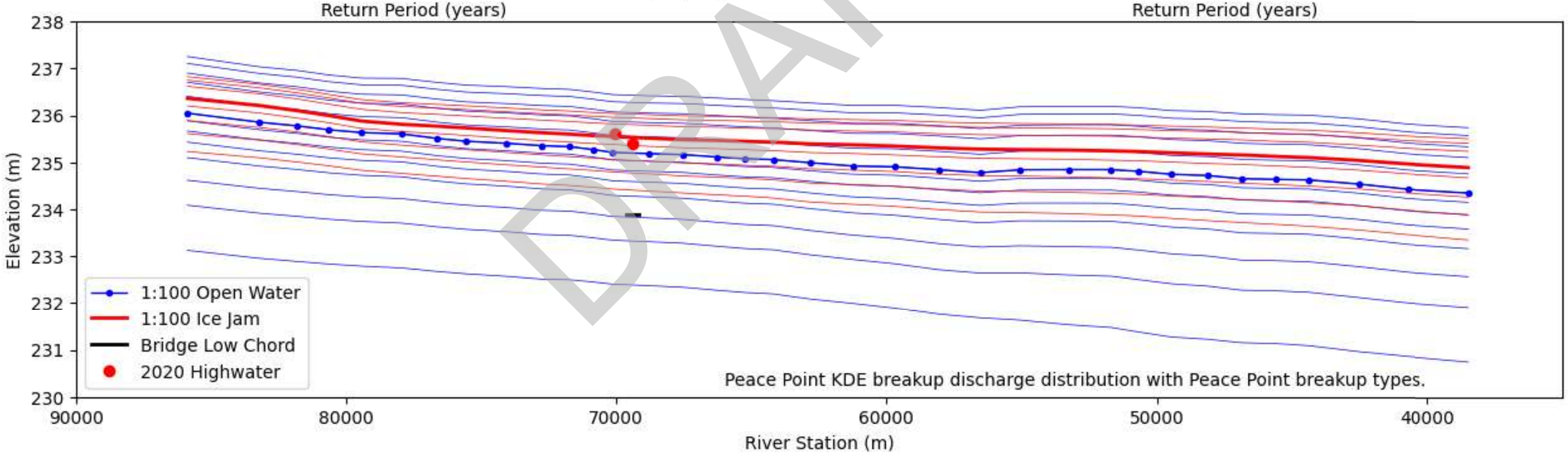
(a)



(b)



(c)



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Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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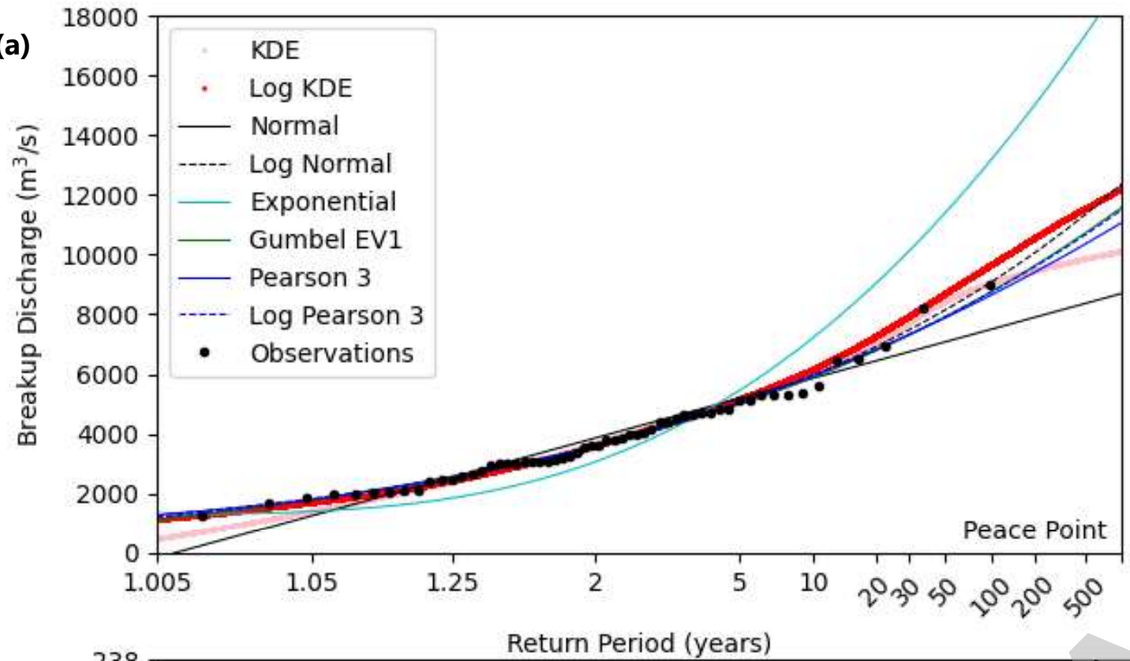
GARDEN RIVER FLOOD STUDY

SCENARIO 7 MONTE CARLO RESULTS
PP Q_{KDE} | $PP_{ICE\ TYPES}$

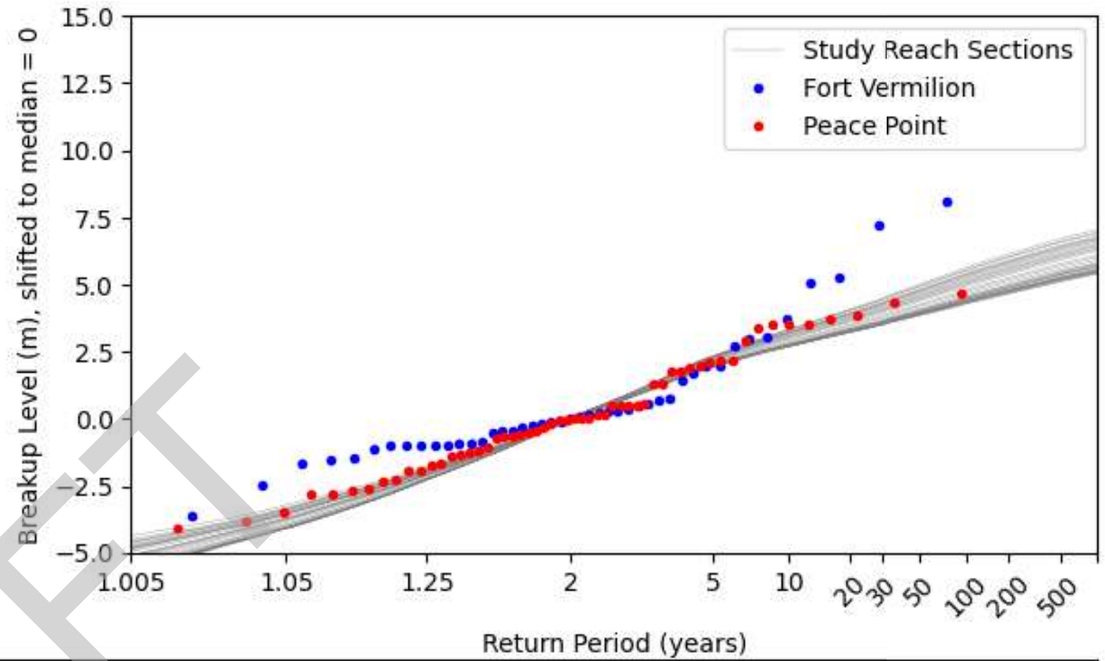
Job: 1009251	Date: Apr-2026	F - 7

Classification: Public

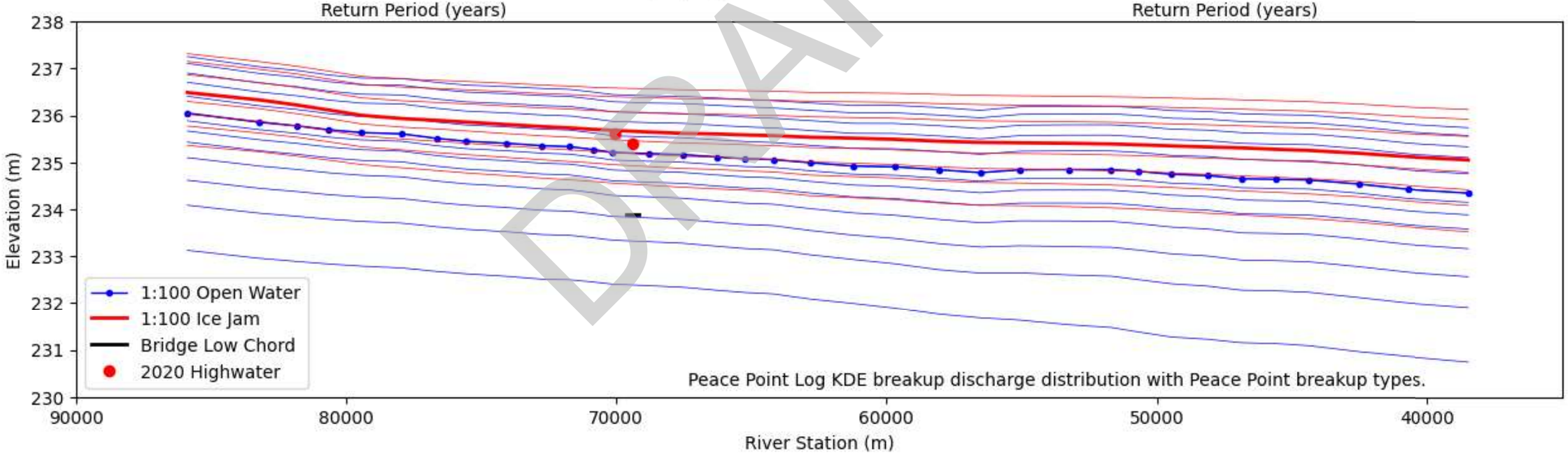
(a)



(b)



(c)



DRAFT

Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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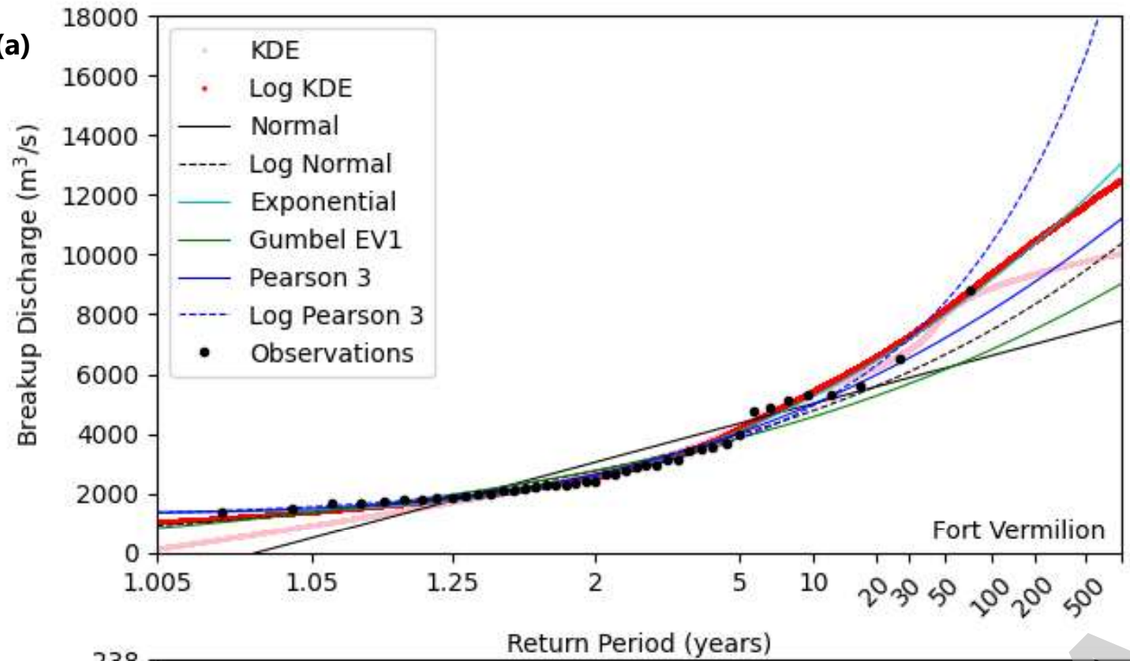
GARDEN RIVER FLOOD STUDY

SCENARIO 8 MONTE CARLO RESULTS
PP $Q_{LOG\ KDE}$ | $PP_{ICE\ TYPES}$

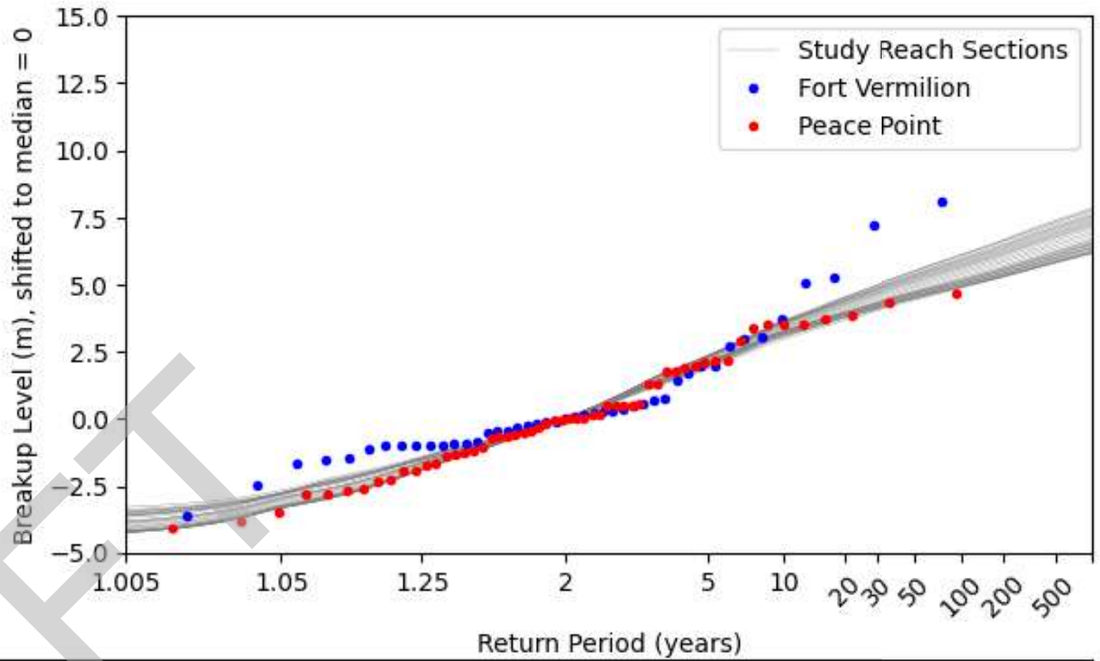
Job: 1009251	Date: Apr-2026	F - 8

Classification: Public

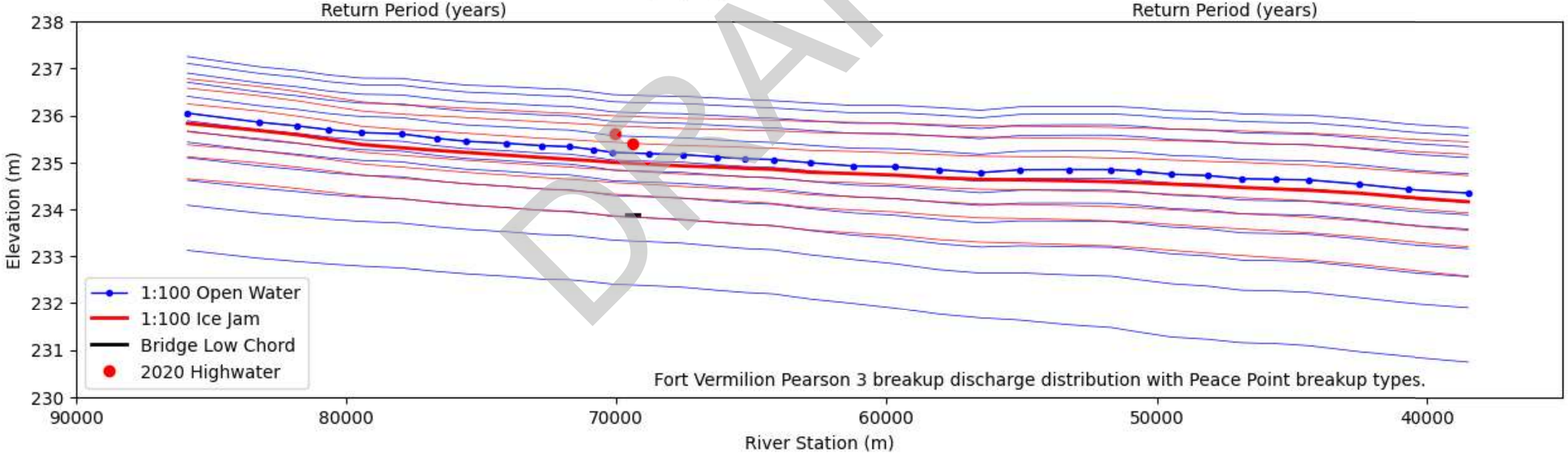
(a)



(b)



(c)



DRAFT

Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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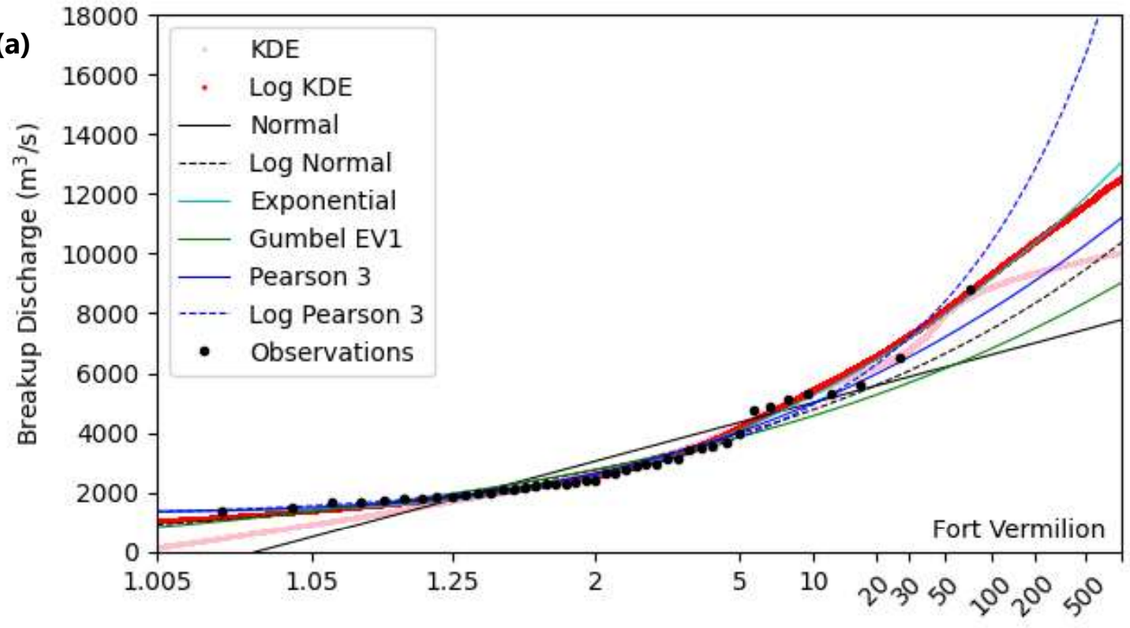
GARDEN RIVER FLOOD STUDY

SCENARIO 9 MONTE CARLO RESULTS
FV Q_{P3} | $PP_{ICE\ TYPES}$

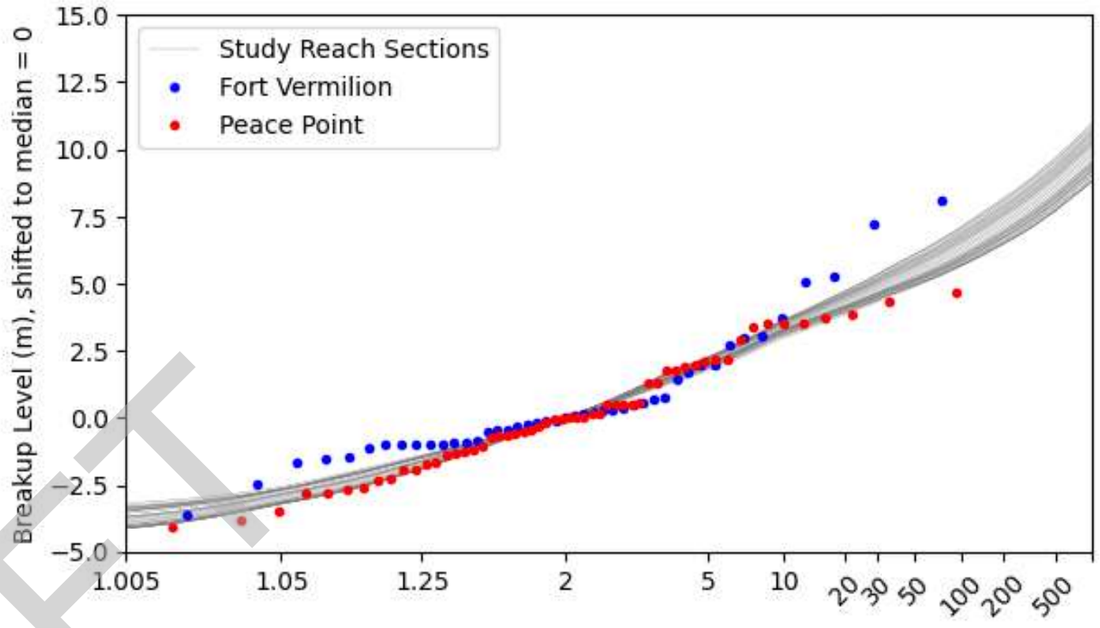
Job: 1009251	Date: Apr-2026	F - 9

Classification: Public

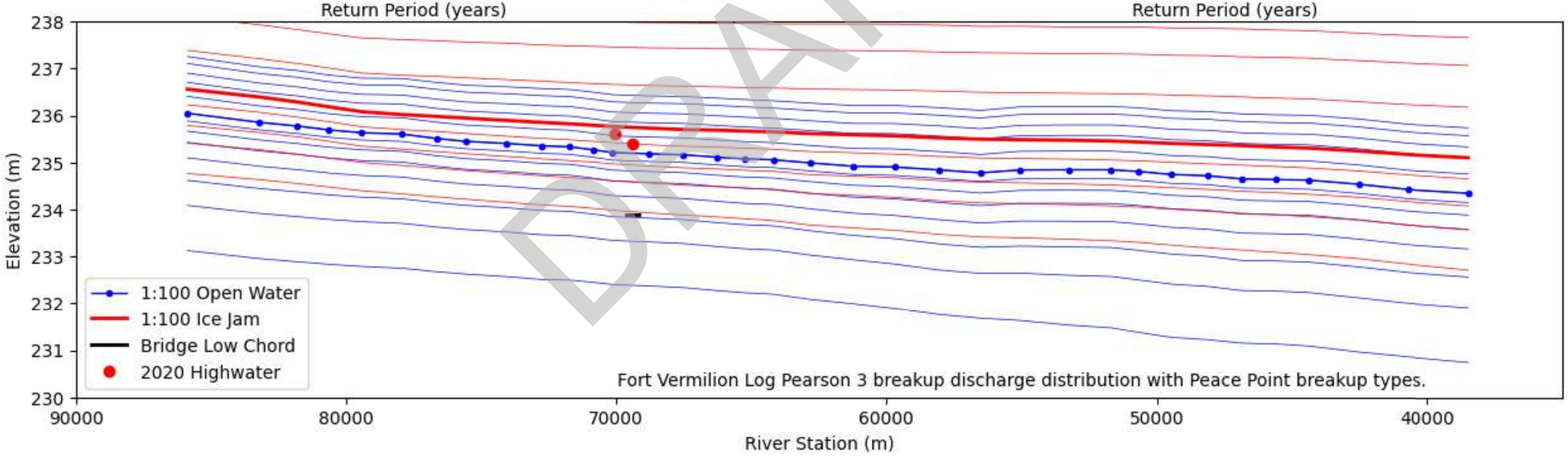
(a)



(b)



(c)



DRAFT

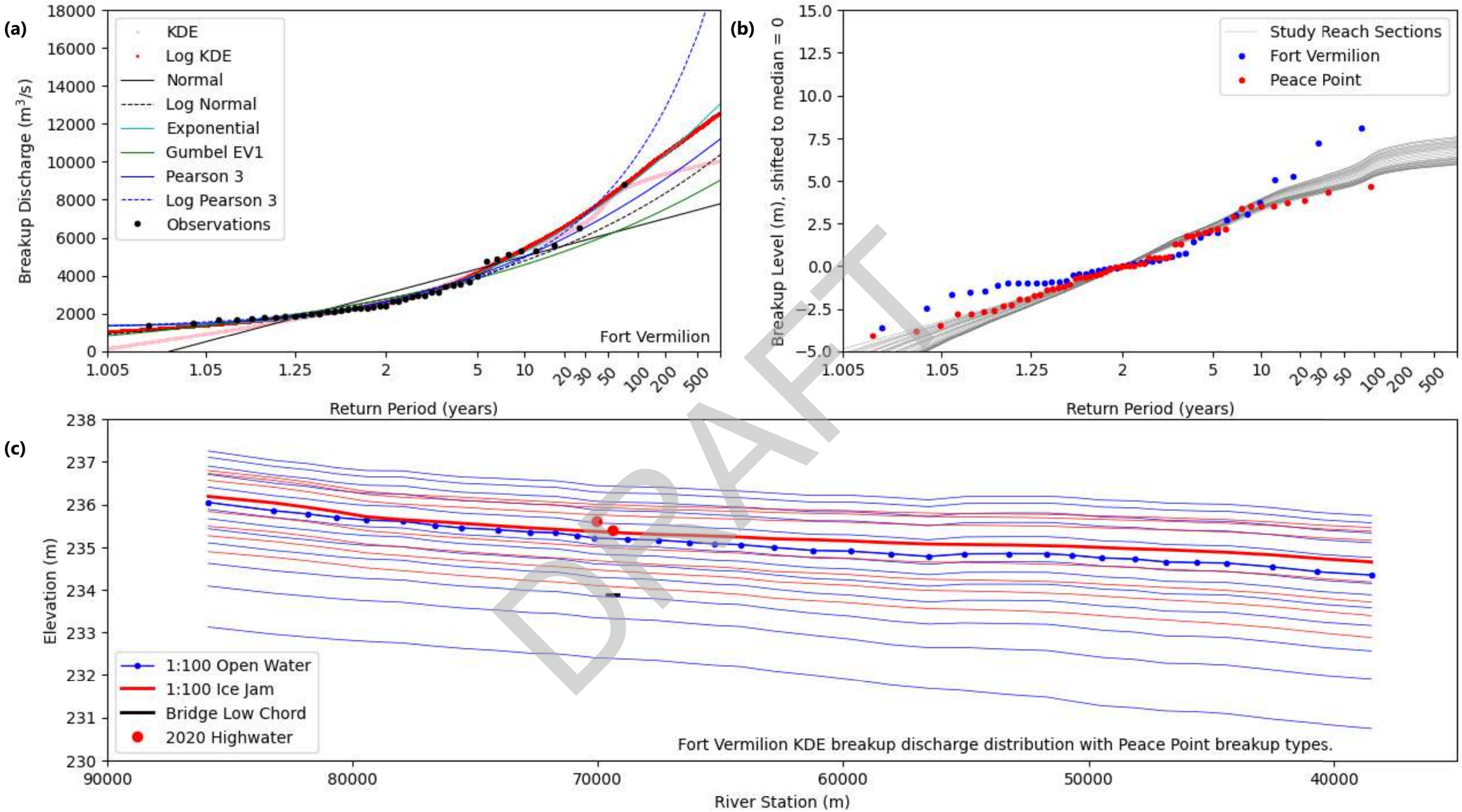
Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

GARDEN RIVER FLOOD STUDY

SCENARIO 10 MONTE CARLO RESULTS
FV Q_{LP3} | $PP_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 10

Classification: Public



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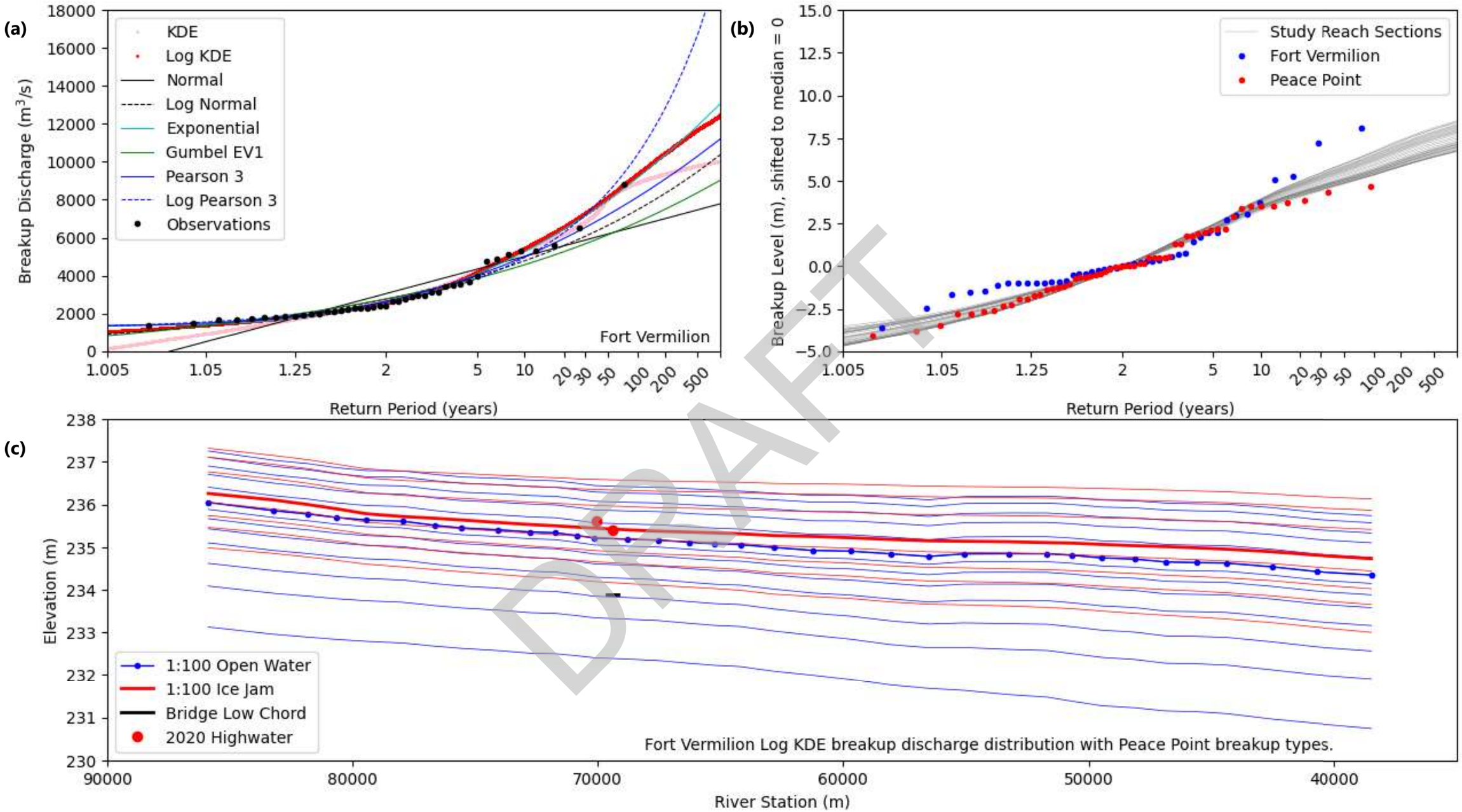
Notes:
a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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c) Garden Creek bridge low chord and corresponding highwater mark are plotted at the mouth of Garden Creek (along Peace River).

GARDEN RIVER FLOOD STUDY

SCENARIO 11 MONTE CARLO RESULTS
FV Q_{KDE} | $PP_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 11

Classification: Public



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Notes: a) KDE and Log KDE distributions are denoted by dots which plot on top of each other – thus appearing as lines.
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GARDEN RIVER FLOOD STUDY

SCENARIO 12 MONTE CARLO RESULTS
FV $Q_{LOG\ KDE}$ | $PP_{ICE\ TYPES}$

Job: 1009251	Date: Apr-2026	F - 12

Classification: Public

APPENDIX G

FLOOD FREQUENCY PROFILE DATA

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Classification: Public

River KM	Model River Station (m)	Open Water Flood Return Period and Discharge (m^3/s)												
		1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
		9,200	11,400	12,900	14,500	15,700	16,600	17,500	18,200	19,900	21,400	22,400	23,500	24,300
		Water Surface Elevation (m) - Peace River												
47.4	85877	233.13	234.09	234.62	235.10	235.43	235.67	235.89	236.05	236.41	236.71	236.90	237.11	237.25
44.7	83205	232.95	233.92	234.45	234.92	235.25	235.48	235.69	235.85	236.21	236.50	236.69	236.89	237.04
43.3	81805	232.89	233.85	234.38	234.85	235.17	235.40	235.62	235.78	236.13	236.42	236.61	236.81	236.96
42.2	80636	232.83	233.79	234.31	234.78	235.10	235.33	235.54	235.69	236.04	236.33	236.52	236.72	236.86
41.0	79445	232.79	233.74	234.27	234.72	235.04	235.27	235.48	235.63	235.98	236.26	236.45	236.65	236.80
39.5	77954	232.75	233.71	234.23	234.69	235.01	235.24	235.45	235.61	235.95	236.24	236.44	236.64	236.79
38.2	76622	232.67	233.63	234.15	234.60	234.91	235.14	235.35	235.51	235.86	236.15	236.35	236.55	236.70
37.1	75566	232.62	233.57	234.09	234.54	234.85	235.08	235.29	235.45	235.80	236.09	236.29	236.50	236.65
35.6	74073	232.57	233.52	234.04	234.49	234.81	235.04	235.25	235.41	235.76	236.05	236.25	236.46	236.61
34.3	72757	232.51	233.46	233.98	234.43	234.75	234.98	235.19	235.36	235.71	236.01	236.21	236.42	236.57
33.3	71729	232.50	233.45	233.96	234.41	234.73	234.96	235.17	235.33	235.69	235.99	236.19	236.40	236.55
32.4	70852	232.45	233.39	233.91	234.35	234.67	234.90	235.11	235.27	235.63	235.93	236.13	236.35	236.50
31.7	70138	232.40	233.34	233.85	234.29	234.61	234.84	235.05	235.21	235.57	235.87	236.08	236.29	236.44
30.3	68796	232.37	233.31	233.82	234.26	234.58	234.81	235.02	235.19	235.54	235.85	236.05	236.27	236.42
29.1	67520	232.34	233.28	233.79	234.23	234.55	234.78	235.00	235.16	235.52	235.83	236.04	236.25	236.41
27.8	66256	232.27	233.21	233.72	234.17	234.49	234.73	234.95	235.11	235.48	235.79	236.00	236.22	236.37
26.8	65243	232.23	233.16	233.68	234.13	234.45	234.69	234.91	235.08	235.44	235.76	235.96	236.19	236.34
25.7	64194	232.20	233.14	233.66	234.11	234.43	234.67	234.89	235.06	235.42	235.73	235.94	236.16	236.31
24.4	62832	232.09	233.03	233.55	234.01	234.35	234.59	234.82	234.99	235.36	235.68	235.89	236.11	236.27
22.8	61247	231.99	232.93	233.45	233.92	234.26	234.52	234.75	234.92	235.30	235.62	235.83	236.06	236.21
21.3	59712	231.89	232.84	233.38	233.87	234.23	234.49	234.73	234.90	235.29	235.61	235.83	236.06	236.22
19.6	58037	231.76	232.71	233.27	233.78	234.15	234.42	234.66	234.84	235.23	235.56	235.78	236.01	236.17
18.1	56529	231.68	232.64	233.20	233.71	234.08	234.35	234.60	234.78	235.17	235.50	235.72	235.95	236.11
16.6	55069	231.63	232.65	233.23	233.75	234.13	234.41	234.66	234.84	235.24	235.57	235.79	236.02	236.18
14.8	53260	231.53	232.60	233.21	233.75	234.13	234.41	234.66	234.85	235.25	235.58	235.80	236.03	236.19
13.2	51692	231.47	232.58	233.20	233.74	234.13	234.41	234.66	234.84	235.24	235.58	235.80	236.03	236.19
12.2	50702	231.38	232.50	233.14	233.69	234.09	234.37	234.62	234.81	235.21	235.55	235.77	236.00	236.17
11.0	49464	231.27	232.41	233.06	233.62	234.02	234.30	234.56	234.75	235.15	235.49	235.71	235.94	236.10
9.7	48119	231.22	232.36	233.01	233.58	233.98	234.27	234.53	234.72	235.12	235.46	235.69	235.92	236.08

DRAFT

River KM	Model River Station (m)	Open Water Flood Return Period and Discharge (m^3/s)												
		1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
		9,200	11,400	12,900	14,500	15,700	16,600	17,500	18,200	19,900	21,400	22,400	23,500	24,300
		Water Surface Elevation (m) - Peace River												
8.4	46856	231.15	232.28	232.92	233.50	233.90	234.20	234.46	234.65	235.06	235.41	235.63	235.87	236.04
7.1	45592	231.13	232.26	232.91	233.48	233.89	234.18	234.44	234.64	235.04	235.39	235.61	235.85	236.02
5.9	44372	231.09	232.23	232.89	233.47	233.88	234.17	234.43	234.63	235.03	235.38	235.60	235.84	236.01
4.1	42534	230.96	232.12	232.78	233.37	233.78	234.08	234.34	234.54	234.95	235.29	235.52	235.76	235.93
2.2	40674	230.86	232.00	232.66	233.25	233.67	233.96	234.23	234.42	234.84	235.18	235.41	235.65	235.81
0.0	38461	230.75	231.91	232.57	233.16	233.58	233.88	234.15	234.35	234.76	235.10	235.33	235.57	235.74

DRAFT

Classification: Public

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
20.2	238.83	239.10	239.23	239.33	239.41	239.45	239.49	239.52	239.59	239.64	239.67	239.71	239.73
20.1	238.82	239.09	239.22	239.32	239.39	239.43	239.48	239.50	239.57	239.62	239.65	239.68	239.70
20.0	238.80	239.07	239.20	239.30	239.37	239.41	239.45	239.48	239.54	239.59	239.62	239.66	239.68
19.9	238.77	239.03	239.15	239.24	239.31	239.34	239.39	239.41	239.47	239.52	239.55	239.58	239.60
19.8	238.73	238.98	239.08	239.16	239.21	239.24	239.28	239.30	239.36	239.41	239.44	239.47	239.49
19.7	238.70	238.92	239.03	239.11	239.16	239.20	239.24	239.26	239.32	239.37	239.39	239.43	239.45
19.6	238.65	238.84	238.93	239.01	239.07	239.10	239.14	239.17	239.23	239.28	239.31	239.35	239.37
19.5	238.62	238.81	238.90	238.98	239.04	239.07	239.11	239.14	239.20	239.25	239.28	239.31	239.33
19.4	238.54	238.73	238.83	238.92	238.98	239.02	239.06	239.09	239.15	239.20	239.23	239.26	239.28
19.3	238.49	238.69	238.79	238.88	238.94	238.98	239.02	239.05	239.11	239.16	239.19	239.23	239.25
19.2	238.44	238.65	238.76	238.84	238.91	238.94	238.98	239.01	239.07	239.12	239.15	239.18	239.20
19.1	238.36	238.59	238.69	238.78	238.84	238.88	238.92	238.94	239.00	239.05	239.08	239.11	239.13
19.0	238.30	238.52	238.63	238.71	238.78	238.81	238.85	238.88	238.94	238.99	239.02	239.06	239.08
18.9	238.24	238.46	238.56	238.64	238.70	238.74	238.78	238.80	238.86	238.91	238.94	238.97	238.99
18.8	238.18	238.41	238.51	238.59	238.65	238.69	238.72	238.75	238.81	238.86	238.88	238.92	238.94
18.7	238.08	238.31	238.41	238.49	238.55	238.59	238.63	238.65	238.72	238.77	238.80	238.83	238.85
18.6	237.94	238.21	238.32	238.41	238.47	238.51	238.55	238.58	238.65	238.70	238.74	238.78	238.80
18.5	237.87	238.15	238.26	238.35	238.42	238.46	238.50	238.53	238.60	238.65	238.69	238.73	238.75
18.4	237.79	238.05	238.17	238.26	238.33	238.37	238.42	238.45	238.53	238.59	238.62	238.66	238.69
18.3	237.73	237.98	238.09	238.18	238.26	238.30	238.35	238.38	238.46	238.52	238.55	238.60	238.62
18.2	237.63	237.86	237.99	238.09	238.17	238.22	238.27	238.31	238.39	238.45	238.49	238.53	238.56
18.1	237.59	237.81	237.93	238.03	238.11	238.15	238.21	238.24	238.32	238.38	238.42	238.46	238.49
18.0	237.52	237.76	237.88	237.98	238.06	238.11	238.16	238.19	238.27	238.33	238.37	238.41	238.44
17.9	237.51	237.75	237.87	237.97	238.05	238.09	238.15	238.18	238.26	238.32	238.36	238.40	238.43
17.8	237.48	237.72	237.84	237.95	238.03	238.07	238.12	238.15	238.23	238.29	238.33	238.38	238.40
17.7	237.45	237.69	237.81	237.91	237.99	238.03	238.09	238.12	238.20	238.26	238.30	238.34	238.37
17.6	237.42	237.66	237.77	237.87	237.95	237.99	238.05	238.08	238.16	238.22	238.26	238.30	238.33
17.5	237.40	237.63	237.74	237.84	237.91	237.95	238.00	238.03	238.11	238.17	238.20	238.25	238.27
17.4	237.37	237.60	237.72	237.81	237.89	237.93	237.98	238.01	238.09	238.15	238.19	238.23	238.26

DRAFT

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
17.3	237.33	237.56	237.68	237.78	237.86	237.90	237.96	237.99	238.07	238.13	238.16	238.21	238.24
17.2	237.26	237.48	237.60	237.71	237.79	237.84	237.89	237.92	238.00	238.06	238.10	238.15	238.17
17.1	237.18	237.39	237.52	237.64	237.72	237.77	237.82	237.85	237.93	238.00	238.04	238.08	238.11
17.0	237.11	237.35	237.48	237.60	237.68	237.72	237.78	237.81	237.89	237.96	238.00	238.04	238.07
16.9	237.05	237.32	237.46	237.57	237.65	237.70	237.75	237.79	237.87	237.93	237.97	238.02	238.05
16.8	237.01	237.29	237.42	237.53	237.62	237.66	237.72	237.75	237.83	237.90	237.94	237.98	238.01
16.7	236.98	237.26	237.39	237.51	237.59	237.63	237.69	237.72	237.80	237.87	237.91	237.95	237.98
16.6	236.94	237.23	237.37	237.48	237.56	237.61	237.66	237.69	237.77	237.84	237.88	237.92	237.95
16.5	236.91	237.20	237.33	237.44	237.52	237.56	237.61	237.65	237.73	237.79	237.83	237.87	237.90
16.4	236.88	237.17	237.30	237.40	237.48	237.52	237.57	237.61	237.68	237.74	237.78	237.83	237.86
16.3	236.85	237.12	237.25	237.35	237.42	237.46	237.51	237.54	237.62	237.68	237.72	237.76	237.79
16.2	236.75	237.02	237.15	237.25	237.33	237.37	237.42	237.45	237.53	237.59	237.63	237.68	237.72
16.1	236.69	236.94	237.07	237.17	237.25	237.29	237.34	237.37	237.45	237.52	237.56	237.61	237.65
16.0	236.66	236.89	237.02	237.12	237.19	237.24	237.29	237.32	237.40	237.47	237.51	237.56	237.60
15.9	236.61	236.86	236.98	237.09	237.16	237.21	237.26	237.29	237.37	237.44	237.48	237.54	237.57
15.8	236.57	236.81	236.92	237.02	237.10	237.14	237.19	237.22	237.30	237.37	237.41	237.47	237.51
15.7	236.52	236.76	236.88	236.98	237.05	237.09	237.14	237.17	237.25	237.32	237.37	237.42	237.46
15.6	236.47	236.73	236.86	236.96	237.03	237.07	237.12	237.15	237.23	237.30	237.35	237.41	237.45
15.5	236.43	236.69	236.82	236.92	236.99	237.03	237.08	237.11	237.20	237.27	237.32	237.38	237.42
15.4	236.38	236.64	236.76	236.85	236.93	236.97	237.01	237.05	237.13	237.20	237.25	237.32	237.37
15.3	236.31	236.58	236.70	236.79	236.86	236.90	236.95	236.98	237.07	237.15	237.20	237.27	237.32
15.2	236.23	236.51	236.63	236.73	236.80	236.84	236.88	236.91	237.00	237.08	237.14	237.21	237.26
15.1	236.15	236.41	236.52	236.62	236.68	236.72	236.77	236.80	236.90	236.99	237.06	237.14	237.20
15.0	236.08	236.35	236.46	236.55	236.62	236.66	236.71	236.74	236.85	236.95	237.02	237.11	237.17
14.9	235.99	236.24	236.35	236.45	236.52	236.57	236.62	236.66	236.78	236.90	236.97	237.07	237.14
14.8	235.94	236.16	236.28	236.37	236.45	236.50	236.55	236.59	236.72	236.85	236.94	237.04	237.11
14.7	235.87	236.10	236.22	236.32	236.39	236.44	236.50	236.55	236.68	236.82	236.91	237.02	237.09
14.6	235.78	236.02	236.14	236.25	236.32	236.37	236.44	236.48	236.64	236.78	236.88	236.99	237.06
14.5	235.72	235.98	236.10	236.20	236.28	236.33	236.39	236.44	236.60	236.76	236.86	236.97	237.05

DRAFT

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
14.4	235.67	235.92	236.04	236.14	236.22	236.27	236.34	236.39	236.56	236.73	236.83	236.95	237.03
14.3	235.61	235.87	235.99	236.09	236.17	236.23	236.30	236.36	236.54	236.71	236.81	236.94	237.02
14.2	235.57	235.81	235.93	236.03	236.11	236.18	236.26	236.32	236.52	236.69	236.80	236.92	237.01
14.1	235.53	235.75	235.87	235.97	236.06	236.13	236.21	236.28	236.49	236.67	236.78	236.91	236.99
14.0	235.50	235.72	235.84	235.94	236.03	236.10	236.18	236.25	236.47	236.66	236.77	236.90	236.98
13.9	235.46	235.70	235.82	235.92	236.01	236.07	236.16	236.23	236.45	236.65	236.76	236.89	236.97
13.8	235.42	235.66	235.77	235.87	235.96	236.03	236.12	236.20	236.43	236.63	236.74	236.88	236.96
13.7	235.39	235.64	235.74	235.83	235.92	235.99	236.09	236.17	236.41	236.61	236.73	236.87	236.95
13.6	235.37	235.62	235.71	235.80	235.89	235.97	236.07	236.15	236.40	236.60	236.72	236.86	236.95
13.5	235.33	235.58	235.67	235.76	235.85	235.93	236.04	236.13	236.38	236.59	236.71	236.85	236.94
13.4	235.28	235.53	235.61	235.70	235.80	235.89	236.01	236.10	236.37	236.59	236.71	236.85	236.94
13.3	235.25	235.48	235.55	235.64	235.75	235.85	235.98	236.08	236.36	236.58	236.70	236.84	236.93
13.2	235.18	235.35	235.43	235.54	235.69	235.80	235.94	236.05	236.34	236.56	236.69	236.83	236.92
13.1	235.08	235.22	235.32	235.47	235.65	235.78	235.92	236.03	236.33	236.56	236.69	236.83	236.92
13.0	234.96	235.12	235.27	235.46	235.64	235.77	235.92	236.03	236.33	236.56	236.69	236.83	236.92
12.9	234.89	235.07	235.24	235.45	235.64	235.77	235.92	236.03	236.33	236.56	236.68	236.83	236.92
12.8	234.82	235.03	235.23	235.44	235.63	235.76	235.91	236.02	236.32	236.55	236.68	236.82	236.92
12.7	234.77	235.02	235.22	235.44	235.62	235.76	235.91	236.02	236.32	236.55	236.68	236.82	236.91
12.6	234.73	235.00	235.21	235.43	235.62	235.75	235.90	236.02	236.32	236.55	236.68	236.82	236.91
12.5	234.69	234.97	235.19	235.41	235.61	235.74	235.89	236.01	236.31	236.54	236.67	236.82	236.91
12.4	234.65	234.93	235.16	235.39	235.59	235.73	235.88	236.00	236.31	236.54	236.67	236.81	236.90
12.3	234.60	234.90	235.13	235.38	235.58	235.72	235.88	235.99	236.30	236.54	236.67	236.81	236.90
12.2	234.53	234.86	235.12	235.37	235.57	235.71	235.87	235.99	236.30	236.53	236.66	236.81	236.90
12.1	234.48	234.84	235.10	235.36	235.56	235.71	235.87	235.99	236.30	236.53	236.66	236.81	236.90
12.0	234.45	234.83	235.10	235.35	235.56	235.70	235.86	235.98	236.30	236.53	236.66	236.80	236.90
11.9	234.42	234.82	235.09	235.35	235.56	235.70	235.86	235.98	236.29	236.53	236.66	236.80	236.90
11.8	234.39	234.81	235.08	235.34	235.55	235.70	235.86	235.98	236.29	236.53	236.66	236.80	236.89
11.7	234.37	234.80	235.08	235.34	235.55	235.69	235.85	235.97	236.29	236.52	236.65	236.80	236.89
11.6	234.35	234.79	235.07	235.33	235.54	235.68	235.85	235.97	236.28	236.52	236.65	236.80	236.89

DRAFT

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
11.5	234.33	234.77	235.05	235.32	235.53	235.68	235.84	235.96	236.28	236.52	236.65	236.79	236.89
11.4	234.29	234.75	235.04	235.30	235.52	235.67	235.83	235.96	236.28	236.51	236.65	236.79	236.89
11.3	234.26	234.74	235.03	235.30	235.51	235.66	235.83	235.95	236.27	236.51	236.64	236.79	236.88
11.2	234.25	234.73	235.02	235.29	235.50	235.65	235.82	235.95	236.27	236.51	236.64	236.78	236.88
11.1	234.23	234.72	235.01	235.28	235.49	235.64	235.81	235.94	236.26	236.50	236.63	236.78	236.87
11.0	234.21	234.70	235.00	235.27	235.49	235.64	235.81	235.93	236.26	236.50	236.63	236.78	236.87
10.9	234.20	234.69	234.98	235.26	235.47	235.63	235.79	235.92	236.25	236.49	236.62	236.77	236.86
10.8	234.17	234.67	234.96	235.24	235.45	235.61	235.78	235.91	236.24	236.48	236.61	236.76	236.86
10.7	234.14	234.66	234.96	235.23	235.45	235.61	235.78	235.91	236.24	236.48	236.61	236.76	236.86
10.6	234.09	234.64	234.95	235.22	235.45	235.60	235.77	235.90	236.23	236.48	236.61	236.76	236.85
10.5	234.06	234.59	234.89	235.16	235.38	235.53	235.71	235.84	236.17	236.42	236.57	236.72	236.83
10.4	234.02	234.51	234.79	235.06	235.28	235.44	235.61	235.74	236.05	236.32	236.49	236.67	236.78
10.3	233.98	234.49	234.76	235.03	235.25	235.41	235.59	235.72	236.03	236.30	236.48	236.66	236.77
10.2	233.95	234.47	234.74	235.01	235.24	235.40	235.58	235.71	236.02	236.29	236.47	236.65	236.77
10.1	233.91	234.43	234.71	234.98	235.21	235.38	235.55	235.69	236.00	236.28	236.46	236.64	236.76
10.0	233.88	234.41	234.69	234.97	235.20	235.37	235.55	235.68	236.00	236.27	236.45	236.64	236.76
9.9	233.86	234.39	234.67	234.95	235.18	235.35	235.53	235.67	235.98	236.26	236.44	236.63	236.75
9.8	233.80	234.35	234.64	234.92	235.16	235.33	235.51	235.65	235.97	236.25	236.43	236.62	236.74
9.7	233.75	234.33	234.63	234.91	235.15	235.32	235.51	235.64	235.97	236.24	236.43	236.62	236.74
9.6	233.70	234.32	234.62	234.91	235.15	235.32	235.51	235.64	235.97	236.24	236.43	236.62	236.74
9.5	233.63	234.30	234.61	234.90	235.14	235.32	235.50	235.64	235.96	236.24	236.43	236.62	236.74
9.4	233.56	234.29	234.60	234.90	235.14	235.32	235.50	235.64	235.96	236.24	236.43	236.62	236.74
9.3	233.52	234.27	234.59	234.89	235.13	235.31	235.49	235.63	235.96	236.24	236.42	236.62	236.74
9.2	233.46	234.24	234.56	234.87	235.12	235.30	235.49	235.63	235.95	236.23	236.42	236.61	236.74
9.1	233.41	234.21	234.54	234.85	235.10	235.29	235.48	235.62	235.95	236.23	236.42	236.61	236.73
9.0	233.37	234.18	234.52	234.83	235.09	235.27	235.47	235.61	235.94	236.22	236.41	236.61	236.73
8.9	233.32	234.13	234.48	234.81	235.07	235.26	235.45	235.60	235.93	236.22	236.40	236.60	236.73
8.8	233.27	234.09	234.45	234.79	235.06	235.25	235.45	235.59	235.93	236.21	236.40	236.60	236.73
8.7	233.22	234.05	234.43	234.78	235.05	235.24	235.44	235.59	235.92	236.21	236.40	236.60	236.72

DRAFT

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
8.6	233.19	234.03	234.42	234.77	235.04	235.24	235.44	235.58	235.92	236.21	236.40	236.60	236.72
8.5	233.14	234.01	234.40	234.76	235.04	235.23	235.43	235.58	235.92	236.20	236.39	236.59	236.72
8.4	233.08	233.97	234.38	234.74	235.02	235.22	235.42	235.57	235.91	236.20	236.39	236.59	236.72
8.3	233.05	233.93	234.34	234.72	235.01	235.21	235.41	235.56	235.90	236.19	236.38	236.58	236.71
8.2	233.02	233.91	234.33	234.71	235.00	235.20	235.41	235.56	235.90	236.19	236.38	236.58	236.71
8.1	232.97	233.88	234.31	234.70	234.99	235.20	235.40	235.55	235.89	236.19	236.38	236.58	236.71
8.0	232.94	233.84	234.28	234.67	234.97	235.18	235.39	235.54	235.89	236.18	236.37	236.57	236.70
7.9	232.88	233.79	234.26	234.66	234.97	235.18	235.39	235.54	235.89	236.18	236.37	236.57	236.70
7.8	232.85	233.75	234.23	234.64	234.95	235.16	235.38	235.53	235.88	236.17	236.37	236.57	236.70
7.7	232.81	233.74	234.21	234.63	234.94	235.16	235.37	235.53	235.88	236.17	236.36	236.57	236.70
7.6	232.77	233.71	234.20	234.62	234.94	235.15	235.37	235.52	235.87	236.17	236.36	236.56	236.69
7.5	232.73	233.69	234.19	234.62	234.93	235.15	235.37	235.52	235.87	236.17	236.36	236.56	236.69
7.4	232.69	233.66	234.17	234.61	234.93	235.15	235.36	235.52	235.87	236.16	236.36	236.56	236.69
7.3	232.66	233.64	234.16	234.60	234.92	235.14	235.36	235.51	235.87	236.16	236.36	236.56	236.69
7.2	232.63	233.62	234.15	234.59	234.91	235.13	235.35	235.51	235.86	236.16	236.35	236.55	236.69
7.1	232.60	233.59	234.13	234.57	234.90	235.12	235.34	235.50	235.85	236.15	236.35	236.55	236.68
7.0	232.58	233.58	234.12	234.56	234.89	235.12	235.33	235.49	235.85	236.15	236.34	236.55	236.68
6.9	232.57	233.57	234.11	234.56	234.89	235.12	235.33	235.49	235.85	236.15	236.34	236.55	236.68
6.8	232.55	233.56	234.10	234.56	234.89	235.11	235.33	235.49	235.85	236.15	236.34	236.55	236.68
6.7	232.54	233.54	234.09	234.55	234.88	235.11	235.33	235.48	235.84	236.14	236.34	236.54	236.67
6.6	232.53	233.54	234.09	234.54	234.87	235.10	235.32	235.48	235.84	236.14	236.34	236.54	236.67
6.5	232.52	233.53	234.08	234.54	234.87	235.10	235.32	235.48	235.84	236.14	236.34	236.54	236.67
6.4	232.50	233.52	234.07	234.53	234.87	235.10	235.32	235.48	235.84	236.14	236.34	236.54	236.67
6.3	232.50	233.51	234.06	234.53	234.86	235.09	235.31	235.48	235.84	236.14	236.33	236.54	236.67
6.2	232.49	233.49	234.05	234.51	234.85	235.08	235.31	235.47	235.84	236.14	236.33	236.54	236.67
6.1	232.48	233.49	234.04	234.51	234.85	235.08	235.31	235.47	235.83	236.14	236.33	236.54	236.67
6.0	232.47	233.47	234.02	234.49	234.82	235.06	235.29	235.45	235.82	236.13	236.33	236.53	236.67
5.9	232.47	233.47	234.02	234.48	234.82	235.05	235.28	235.44	235.80	236.11	236.30	236.51	236.64
5.8	232.46	233.46	234.01	234.48	234.81	235.05	235.27	235.44	235.80	236.10	236.30	236.51	236.64

DRAFT

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
5.7	232.45	233.45	234.01	234.47	234.81	235.04	235.27	235.43	235.80	236.10	236.30	236.51	236.64
5.6	232.45	233.45	234.00	234.46	234.80	235.03	235.26	235.42	235.79	236.09	236.29	236.50	236.63
5.5	232.45	233.44	233.99	234.45	234.78	235.02	235.24	235.41	235.78	236.08	236.28	236.49	236.62
5.4	232.44	233.43	233.98	234.44	234.77	235.01	235.24	235.40	235.77	236.08	236.28	236.48	236.62
5.3	232.44	233.43	233.97	234.43	234.77	235.00	235.23	235.39	235.76	236.07	236.27	236.48	236.61
5.2	232.44	233.42	233.97	234.42	234.76	234.99	235.22	235.39	235.75	236.06	236.26	236.47	236.61
5.1	232.43	233.41	233.95	234.41	234.75	234.98	235.21	235.38	235.75	236.06	236.26	236.47	236.61
5.0	232.43	233.40	233.95	234.40	234.73	234.97	235.20	235.36	235.73	236.04	236.24	236.45	236.59
4.9	232.42	233.40	233.94	234.40	234.73	234.96	235.19	235.36	235.72	236.03	236.24	236.45	236.59
4.8	232.42	233.40	233.94	234.39	234.72	234.96	235.19	235.35	235.72	236.03	236.23	236.44	236.58
4.7	232.42	233.40	233.94	234.39	234.72	234.96	235.18	235.35	235.72	236.03	236.23	236.44	236.58
4.6	232.42	233.40	233.93	234.39	234.72	234.96	235.18	235.35	235.71	236.02	236.23	236.44	236.58
4.5	232.42	233.40	233.93	234.39	234.72	234.96	235.18	235.35	235.71	236.02	236.23	236.44	236.58
4.4	232.42	233.39	233.93	234.39	234.72	234.96	235.18	235.35	235.71	236.02	236.22	236.44	236.58
4.3	232.42	233.39	233.93	234.39	234.72	234.96	235.18	235.35	235.71	236.02	236.23	236.44	236.58
4.2	232.42	233.39	233.93	234.39	234.72	234.95	235.18	235.34	235.71	236.02	236.22	236.44	236.58
4.1	232.42	233.39	233.93	234.38	234.72	234.95	235.18	235.34	235.71	236.02	236.22	236.43	236.58
4.0	232.42	233.39	233.92	234.38	234.70	234.94	235.17	235.33	235.70	236.01	236.21	236.42	236.57
3.9	232.42	233.38	233.92	234.37	234.70	234.94	235.16	235.33	235.69	236.00	236.20	236.42	236.56
3.8	232.42	233.38	233.92	234.37	234.70	234.93	235.16	235.32	235.69	236.00	236.20	236.41	236.56
3.7	232.41	233.38	233.91	234.37	234.69	234.93	235.15	235.32	235.69	235.99	236.20	236.41	236.55
3.6	232.41	233.38	233.91	234.37	234.69	234.93	235.15	235.32	235.69	235.99	236.20	236.41	236.55
3.5	232.41	233.38	233.91	234.36	234.69	234.92	235.15	235.31	235.68	235.99	236.19	236.40	236.55
3.4	232.41	233.37	233.91	234.35	234.68	234.92	235.14	235.30	235.67	235.98	236.18	236.40	236.54
3.3	232.41	233.37	233.90	234.35	234.68	234.91	235.14	235.30	235.67	235.98	236.18	236.39	236.54
3.2	232.41	233.37	233.90	234.35	234.67	234.91	235.13	235.30	235.66	235.97	236.17	236.39	236.53
3.1	232.41	233.37	233.90	234.34	234.67	234.91	235.13	235.29	235.66	235.97	236.17	236.39	236.53
3.0	232.41	233.37	233.89	234.34	234.67	234.90	235.12	235.29	235.65	235.96	236.17	236.38	236.53
2.9	232.41	233.36	233.89	234.34	234.66	234.90	235.12	235.28	235.65	235.96	236.16	236.37	236.52

DRAFT

River KM	Open Water Flood Return Period and Discharge (m^3/s)												
	1:2	1:5	1:10	1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500	1:750	1:1000
	17	37	53	68	81	89	99	105	121	134	142	152	158
	Water Surface Elevation (m) - Garden Creek												
2.8	232.41	233.36	233.89	234.33	234.66	234.89	235.11	235.28	235.64	235.95	236.15	236.37	236.52
2.7	232.41	233.36	233.89	234.33	234.66	234.89	235.11	235.28	235.64	235.95	236.15	236.37	236.51
2.6	232.41	233.36	233.88	234.33	234.65	234.89	235.11	235.27	235.63	235.94	236.15	236.36	236.51
2.5	232.41	233.36	233.88	234.33	234.65	234.88	235.10	235.27	235.63	235.94	236.14	236.36	236.51
2.4	232.41	233.36	233.88	234.32	234.65	234.88	235.10	235.26	235.63	235.94	236.14	236.35	236.50
2.3	232.40	233.36	233.88	234.32	234.64	234.88	235.10	235.26	235.62	235.93	236.13	236.35	236.50
2.2	232.40	233.35	233.88	234.32	234.64	234.87	235.09	235.25	235.62	235.92	236.13	236.34	236.49
2.1	232.40	233.35	233.88	234.32	234.64	234.87	235.09	235.25	235.62	235.92	236.12	236.34	236.49
2.0	232.40	233.35	233.88	234.32	234.64	234.87	235.09	235.25	235.62	235.92	236.13	236.34	236.49
1.9	232.40	233.35	233.87	234.32	234.64	234.87	235.09	235.25	235.61	235.92	236.12	236.34	236.49
1.8	232.40	233.35	233.87	234.31	234.63	234.86	235.08	235.25	235.61	235.91	236.12	236.33	236.48
1.7	232.40	233.35	233.87	234.31	234.63	234.86	235.08	235.24	235.60	235.91	236.11	236.33	236.48
1.6	232.40	233.35	233.87	234.31	234.63	234.86	235.08	235.24	235.60	235.91	236.11	236.32	236.48
1.5	232.40	233.35	233.87	234.30	234.62	234.86	235.07	235.24	235.60	235.90	236.11	236.32	236.47
1.4	232.40	233.35	233.87	234.30	234.62	234.85	235.07	235.23	235.59	235.90	236.10	236.32	236.47
1.3	232.40	233.35	233.86	234.30	234.62	234.85	235.07	235.23	235.59	235.90	236.10	236.32	236.47
1.2	232.40	233.34	233.86	234.30	234.62	234.85	235.07	235.23	235.59	235.89	236.10	236.31	236.46
1.1	232.40	233.34	233.86	234.30	234.61	234.85	235.06	235.22	235.58	235.89	236.09	236.31	236.46
1.0	232.39	233.33	233.85	234.29	234.61	234.84	235.06	235.22	235.58	235.88	236.09	236.30	236.45
0.9	232.39	233.33	233.85	234.29	234.61	234.84	235.05	235.22	235.57	235.88	236.08	236.30	236.45
0.8	232.39	233.33	233.84	234.29	234.60	234.84	235.05	235.21	235.57	235.88	236.08	236.30	236.45
0.7	232.39	233.33	233.84	234.29	234.60	234.83	235.05	235.21	235.57	235.87	236.08	236.29	236.44
0.6	232.39	233.33	233.84	234.29	234.60	234.83	235.05	235.21	235.56	235.87	236.07	236.29	236.44
0.5	232.39	233.33	233.84	234.28	234.60	234.83	235.04	235.21	235.56	235.87	236.07	236.29	236.44
0.4	232.39	233.33	233.84	234.28	234.60	234.83	235.04	235.20	235.56	235.87	236.07	236.28	236.44
0.3	232.39	233.33	233.84	234.28	234.59	234.83	235.04	235.20	235.56	235.86	236.07	236.28	236.43
0.2	232.39	233.33	233.84	234.28	234.59	234.82	235.04	235.20	235.56	235.86	236.06	236.28	236.43
0.1	232.39	233.32	233.83	234.28	234.59	234.82	235.04	235.20	235.55	235.86	236.06	236.28	236.43
0.0	232.39	233.32	233.83	234.28	234.59	234.82	235.03	235.20	235.55	235.86	236.06	236.28	236.43

DRAFT

River KM	Model River Station (m)	Ice Jam Flood Return Period							
		1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500
		Water Surface Elevation (m) - Peace River							
47.4	85877	234.98	235.46	235.74	236.05	236.26	236.77	237.11	237.32
44.7	83205	234.85	235.33	235.59	235.89	236.11	236.60	236.94	237.15
43.3	81805	234.77	235.23	235.50	235.80	236.00	236.50	236.84	237.05
42.2	80636	234.69	235.14	235.40	235.70	235.90	236.39	236.73	236.95
41.0	79445	234.60	235.05	235.30	235.59	235.78	236.28	236.62	236.84
39.5	77954	234.53	234.98	235.24	235.52	235.72	236.21	236.56	236.78
38.2	76622	234.47	234.92	235.18	235.47	235.68	236.17	236.53	236.75
37.1	75566	234.42	234.87	235.13	235.43	235.64	236.14	236.50	236.73
35.6	74073	234.36	234.81	235.08	235.37	235.58	236.10	236.46	236.69
34.3	72757	234.30	234.76	235.03	235.32	235.53	236.06	236.42	236.65
33.3	71729	234.27	234.72	234.99	235.29	235.50	236.03	236.40	236.63
32.4	70852	234.23	234.69	234.95	235.26	235.47	236.00	236.37	236.60
31.7	70138	234.19	234.66	234.92	235.23	235.45	235.98	236.35	236.59
30.3	68796	234.14	234.61	234.88	235.19	235.40	235.95	236.33	236.57
29.1	67520	234.10	234.57	234.84	235.15	235.37	235.92	236.31	236.55
27.8	66256	234.06	234.53	234.81	235.13	235.35	235.91	236.30	236.54
26.8	65243	234.03	234.51	234.79	235.11	235.33	235.90	236.29	236.53
25.7	64194	233.99	234.47	234.76	235.09	235.31	235.89	236.28	236.52
24.4	62832	233.90	234.40	234.69	235.03	235.27	235.85	236.25	236.50
22.8	61247	233.84	234.36	234.66	235.01	235.25	235.84	236.24	236.49
21.3	59712	233.79	234.32	234.63	234.98	235.22	235.82	236.23	236.48
19.6	58037	233.71	234.25	234.56	234.92	235.18	235.78	236.20	236.45
18.1	56529	233.66	234.20	234.52	234.89	235.15	235.76	236.18	236.43
16.6	55069	233.64	234.19	234.51	234.88	235.14	235.75	236.17	236.42
14.8	53260	233.62	234.17	234.49	234.86	235.13	235.74	236.16	236.41
13.2	51692	233.58	234.15	234.47	234.84	235.11	235.73	236.15	236.40
12.2	50702	233.56	234.13	234.45	234.83	235.09	235.71	236.14	236.39
11.0	49464	233.50	234.08	234.42	234.80	235.06	235.69	236.12	236.38
9.7	48119	233.45	234.04	234.38	234.77	235.03	235.67	236.10	236.36

DRAFT

River KM	Model River Station (m)	Ice Jam Flood Return Period							
		1:20	1:35	1:50	1:75	1:100	1:200	1:350	1:500
		Water Surface Elevation (m) - Peace River							
8.4	46856	233.40	234.00	234.34	234.74	235.01	235.65	236.08	236.34
7.1	45592	233.36	233.97	234.31	234.70	234.98	235.62	236.06	236.32
5.9	44372	233.31	233.93	234.28	234.67	234.95	235.60	236.04	236.30
4.1	42534	233.23	233.86	234.21	234.61	234.89	235.54	235.99	236.25
2.2	40674	233.12	233.76	234.12	234.53	234.81	235.47	235.92	236.18
0.0	38461	233.00	233.66	234.03	234.44	234.73	235.42	235.87	236.13

DRAFT

Classification: Public

APPENDIX H

OPEN WATER FLOOD INUNDATION MAPPING LIBRARY

Provided under separate cover.

DRAFT

Classification: Public

APPENDIX I

ICE JAM INUNDATION MAPPING LIBRARY

Provided under separate cover.

DRAFT

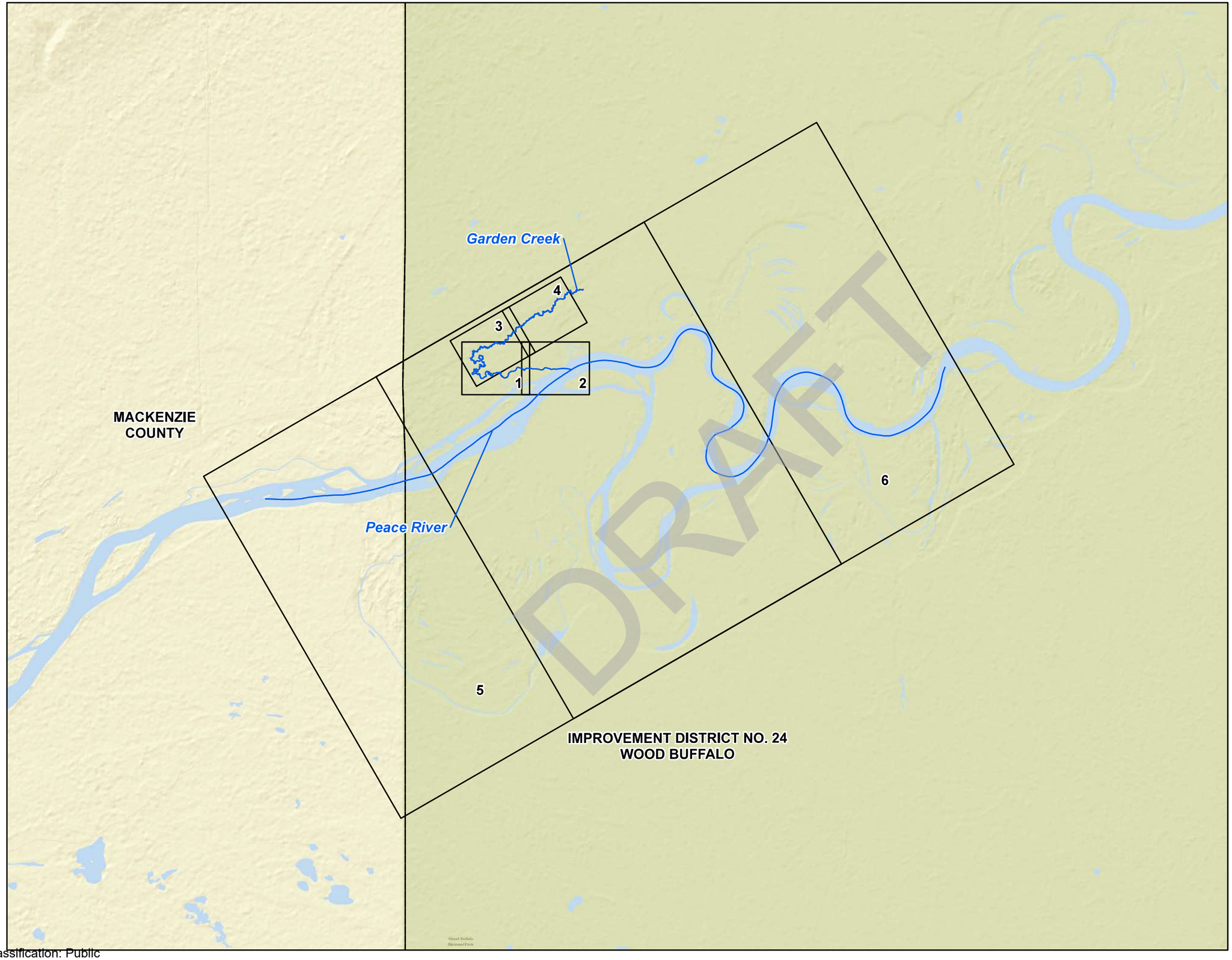
Classification: Public

APPENDIX J

OPEN WATER FLOODWAY CRITERIA MAP

DRAFT

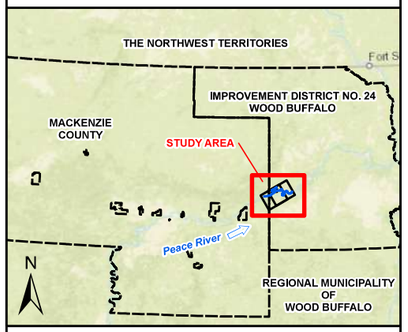
Classification: Public



DRAFT

Alberta Canada

nhc



- FLOW DIRECTION
- RIVER CENTRELINE
- MAP SHEETS
- COUNTY DISTRICT

SCALE - 1:180,000

0 2.5 5 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

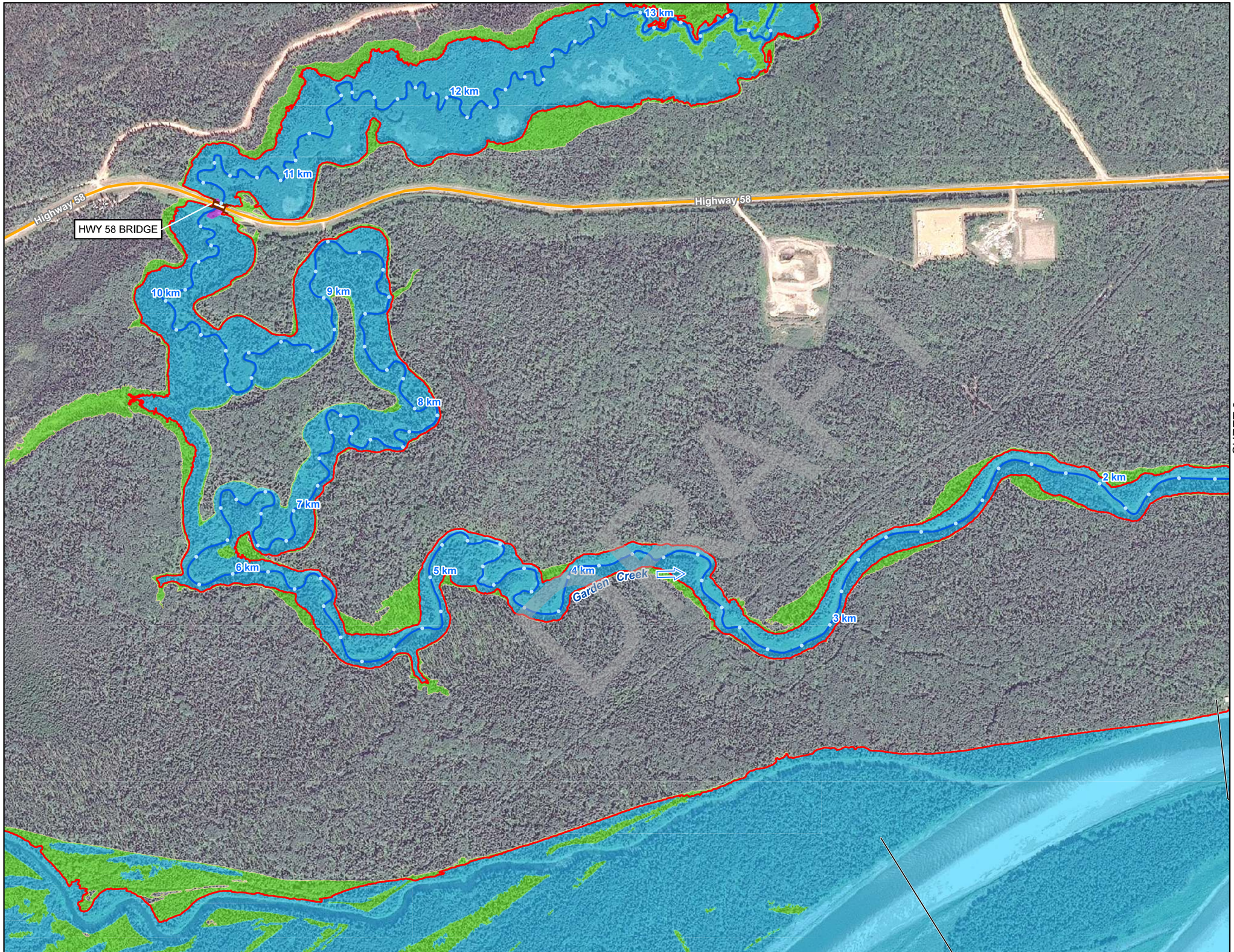
INDEX MAP

SHEET 1 OF 1

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Classification: Public

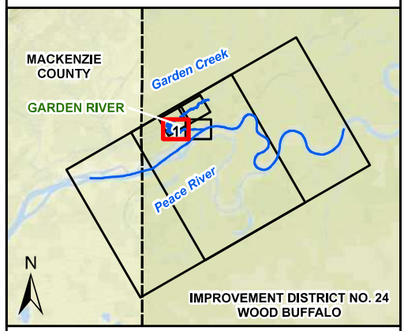
SHEET 3



SHEET 2

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- FLOW DIRECTION
- 1D MODEL SECTIONS
- 1D VELOCITY >= 1 m/s
- 2D VELOCITY >= 1 m/s
- DEPTH >= 1 m
- 1:100 OPEN WATER FLOOD EXTENT
- PROPOSED OPEN WATER FLOODWAY LIMIT

SCALE - 1:10,000
0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

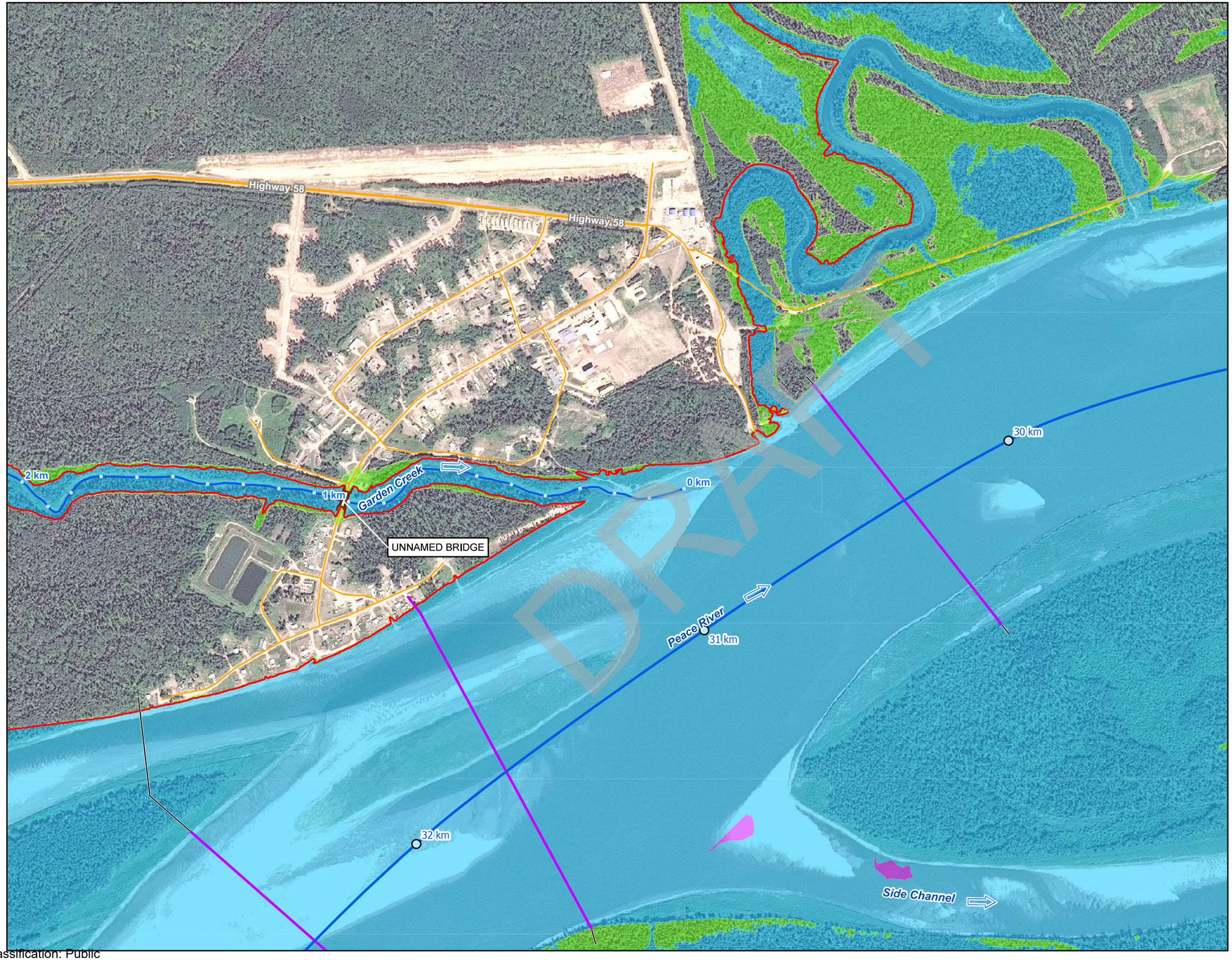
GARDEN RIVER FLOOD STUDY
OPEN WATER FLOODWAY CRITERIA MAP

SHEET 1 OF 6

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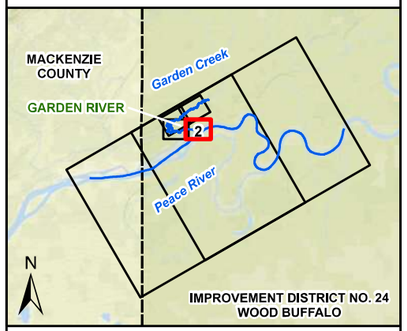
Classification: Public

SHEET 1



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- 1 KM RIVER STATION
- FLOW DIRECTION
- 1D MODEL SECTIONS
- 1D VELOCITY >= 1 m/s
- 2D VELOCITY >= 1 m/s
- DEPTH >= 1 m
- 1:100 OPEN WATER FLOOD EXTENT
- PROPOSED OPEN WATER FLOODWAY LIMIT

SCALE - 1:10,000
0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

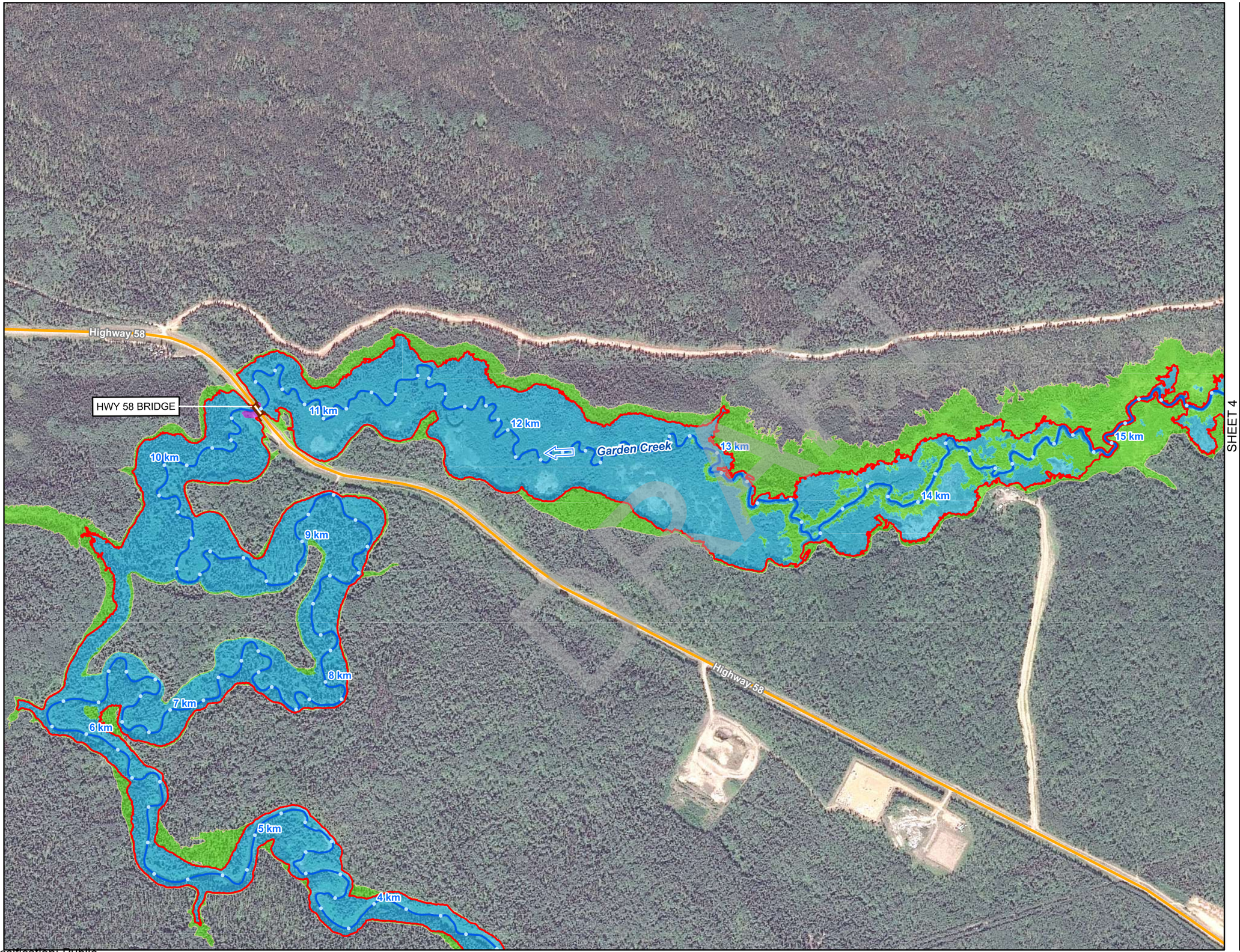
GARDEN RIVER FLOOD STUDY
OPEN WATER FLOODWAY CRITERIA MAP

SHEET 2 OF 6

DRAFT

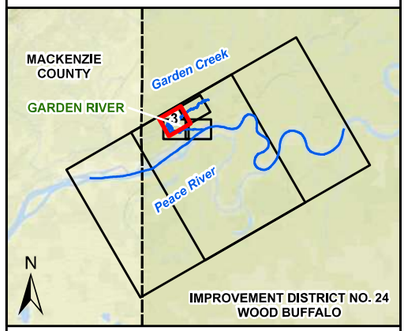
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Classification: Public



Alberta Canada

nhc



SHEET 4

- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- FLOW DIRECTION
- 1D MODEL SECTIONS
- 1D VELOCITY >= 1 m/s
- 2D VELOCITY >= 1 m/s
- DEPTH >= 1 m
- 1:100 OPEN WATER FLOOD EXTENT
- PROPOSED OPEN WATER FLOODWAY LIMIT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

Coordinate System: NAD 1983 CSRS 3TM 114; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY
OPEN WATER FLOODWAY CRITERIA MAP

SHEET 3 OF 6

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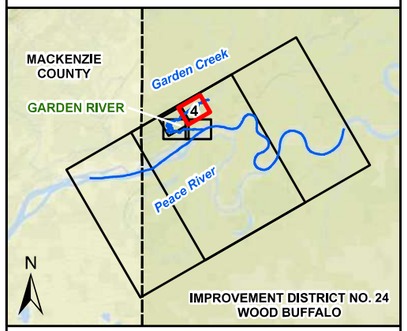
Classification: Public

SHEET 3



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- FLOW DIRECTION
- 1D MODEL SECTIONS
- 1D VELOCITY >= 1 m/s
- 2D VELOCITY >= 1 m/s
- DEPTH >= 1 m
- 1:100 OPEN WATER FLOOD EXTENT
- PROPOSED OPEN WATER FLOODWAY LIMIT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

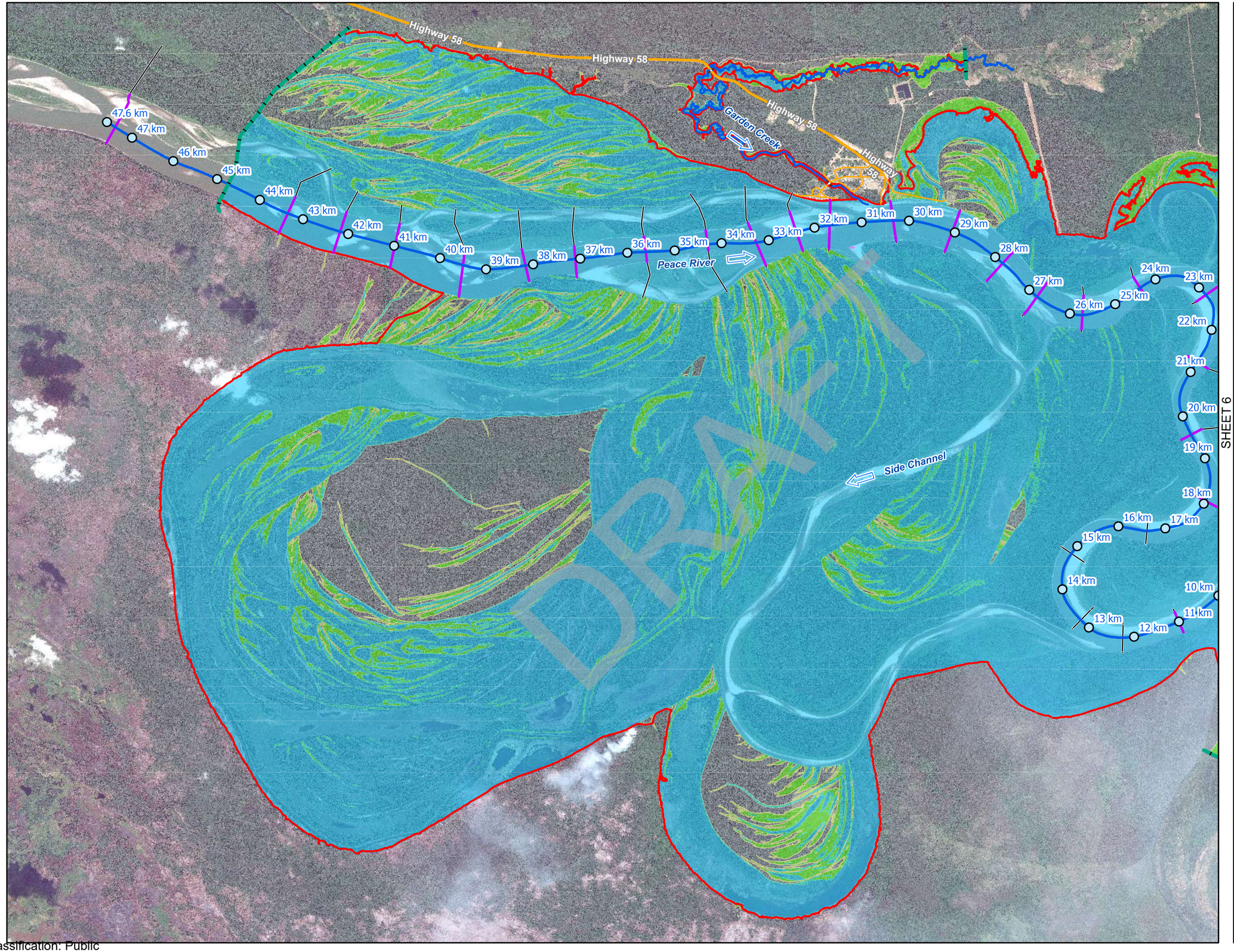
GARDEN RIVER FLOOD STUDY

OPEN WATER FLOODWAY CRITERIA MAP

SHEET 4 OF 6

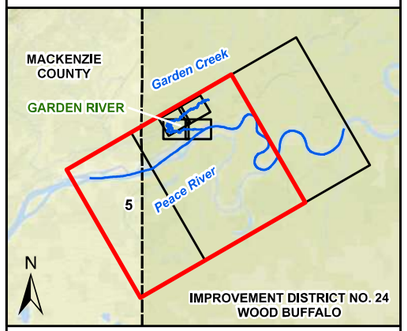
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Classification: Public



Alberta Canada

nhc



SHEET 6

- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- 1D MODEL SECTIONS
- 1D VELOCITY >= 1 m/s
- 2D VELOCITY >= 1 m/s
- DEPTH >= 1 m
- 1:100 OPEN WATER FLOOD EXTENT
- PROPOSED OPEN WATER FLOODWAY LIMIT

SCALE - 1:75,000

0 0.5 1 1.5 2 2.5 3 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

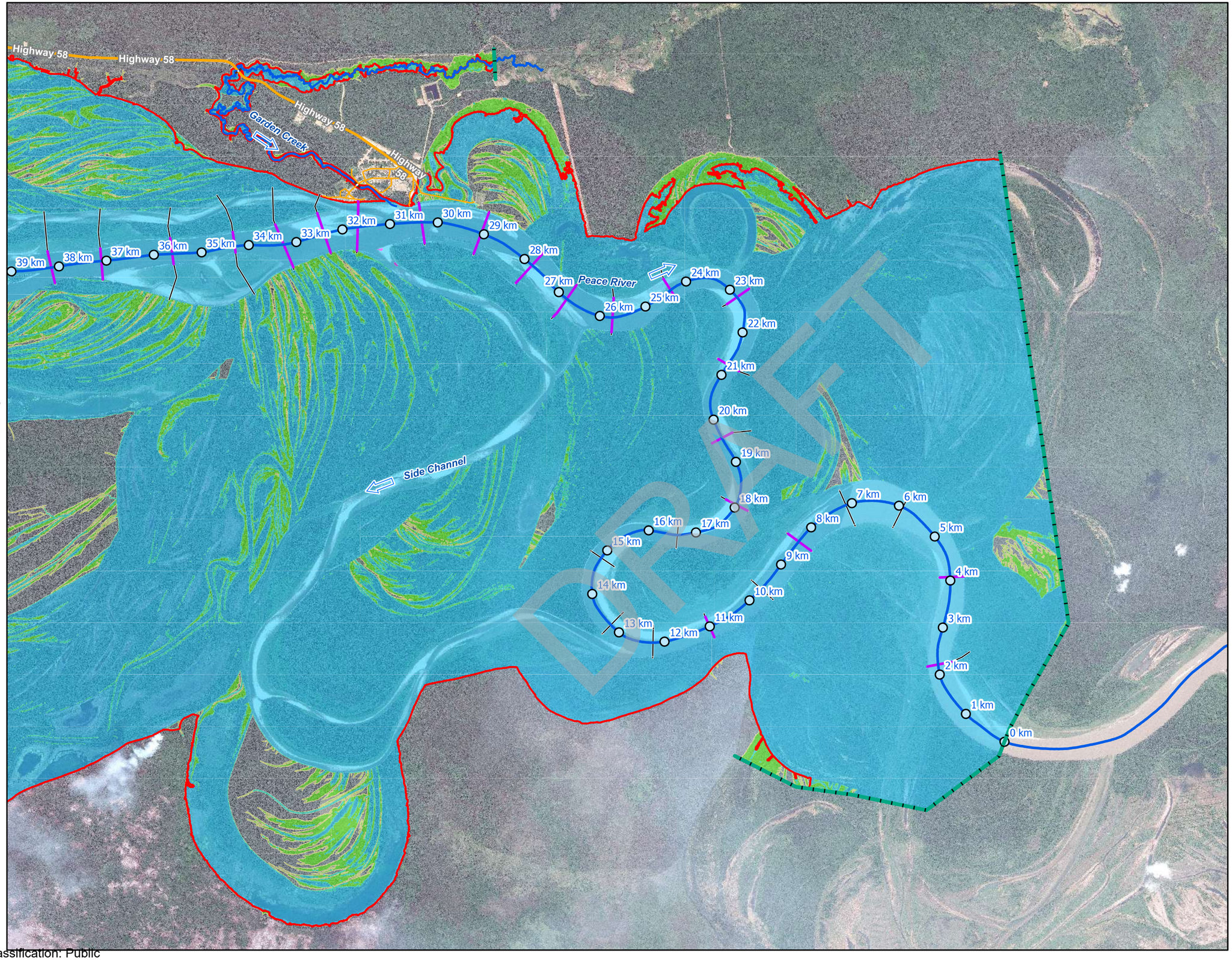
GARDEN RIVER FLOOD STUDY

OPEN WATER FLOODWAY CRITERIA MAP

SHEET 5 OF 6

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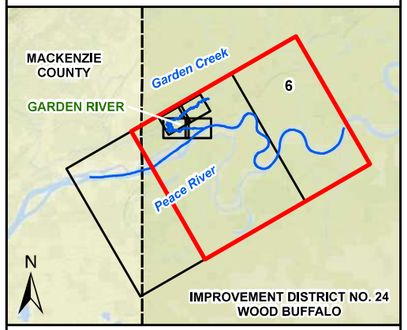
Classification: Public



SHEET 5

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- 1D MODEL SECTIONS
- 1D VELOCITY >= 1 m/s
- 2D VELOCITY >= 1 m/s
- DEPTH >= 1 m
- 1:100 OPEN WATER FLOOD EXTENT
- PROPOSED OPEN WATER FLOODWAY LIMIT

SCALE - 1:75,000

0 0.5 1 1.5 2 2.5 3 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

OPEN WATER FLOODWAY CRITERIA MAP

SHEET 6 OF 6

DRAFT

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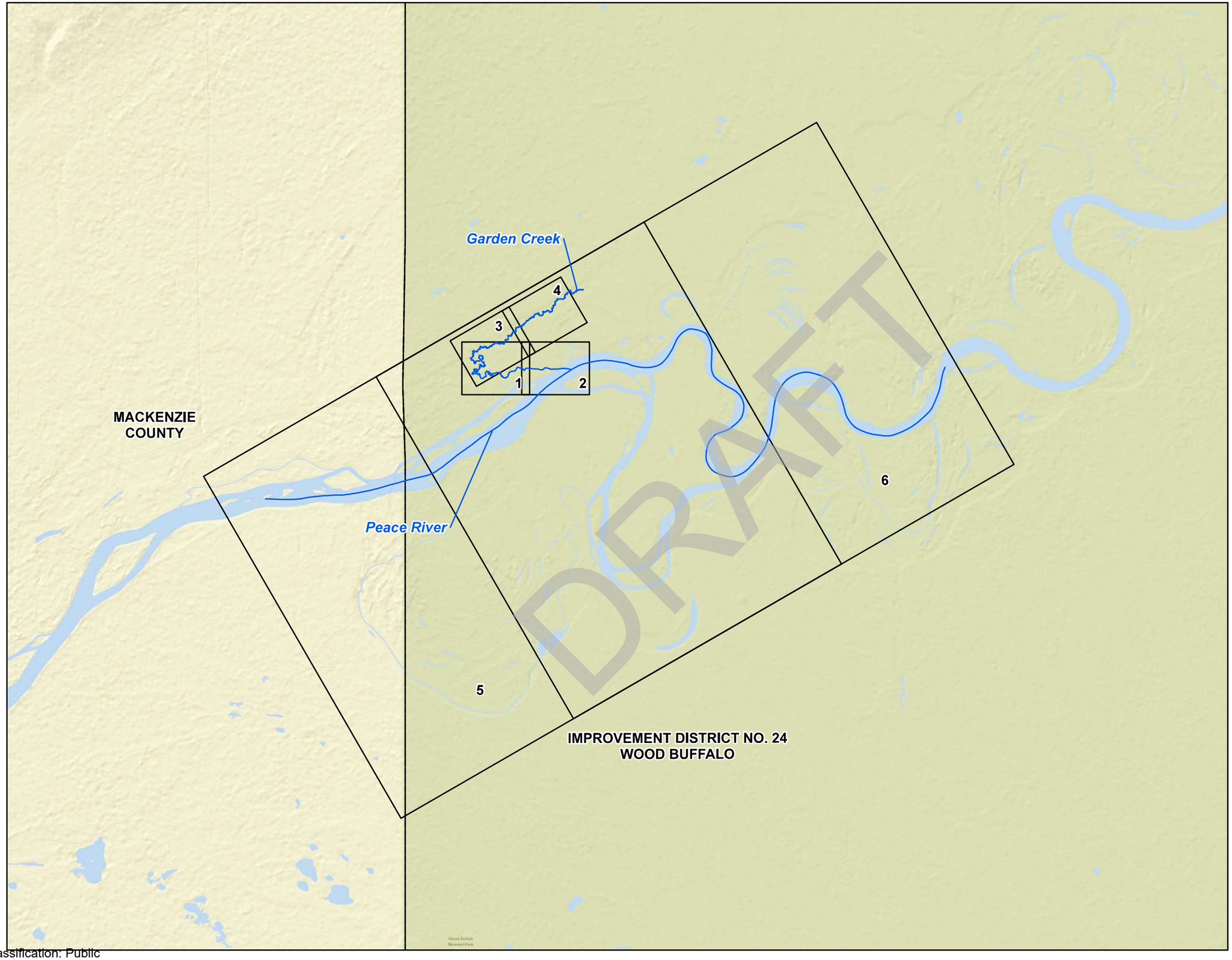
Classification: Public

APPENDIX K

ICE JAM FLOODWAY CRITERIA MAP

DRAFT

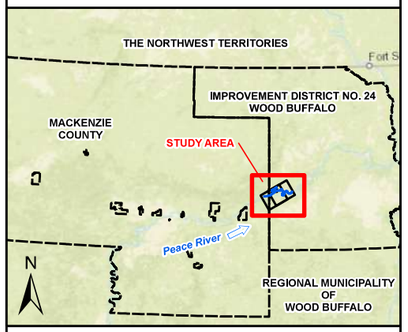
Classification: Public



DRAFT

Alberta Canada

nhc



- FLOW DIRECTION
- RIVER CENTRELINE
- MAP SHEETS
- COUNTY DISTRICT

SCALE - 1:180,000

0 2.5 5 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

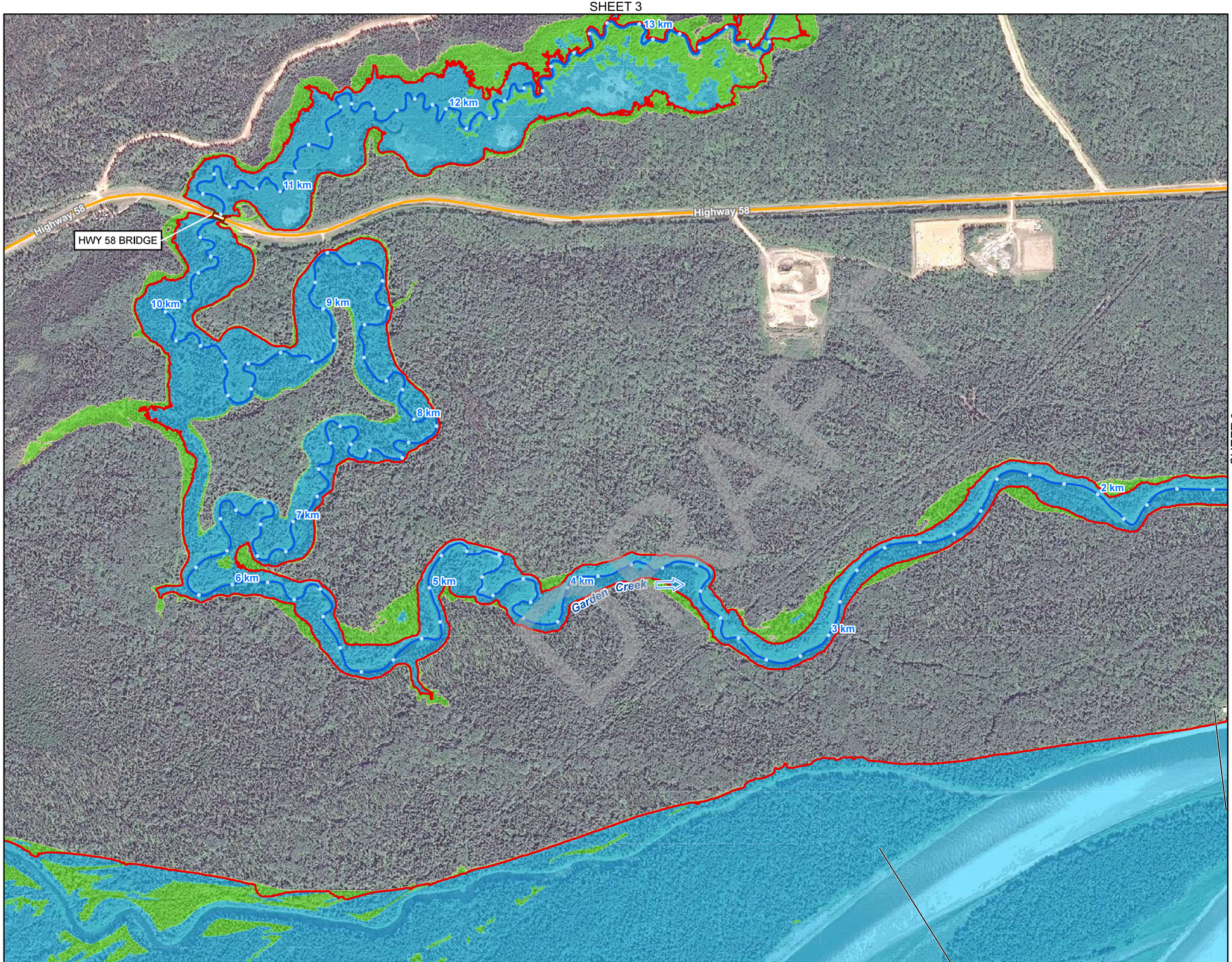
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SHEET 1 OF 1

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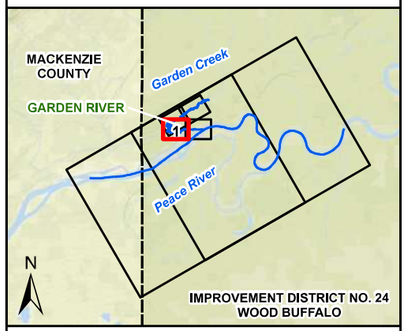
SHEET 3



SHEET 2

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- FLOW DIRECTION
- GARDEN CREEK BANKS
- 1D MODEL SECTIONS
- DEPTH >= 1 m
- 1:100 ICE JAM FLOOD EXTENT
- PROPOSED ICE JAM FLOODWAY LIMIT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

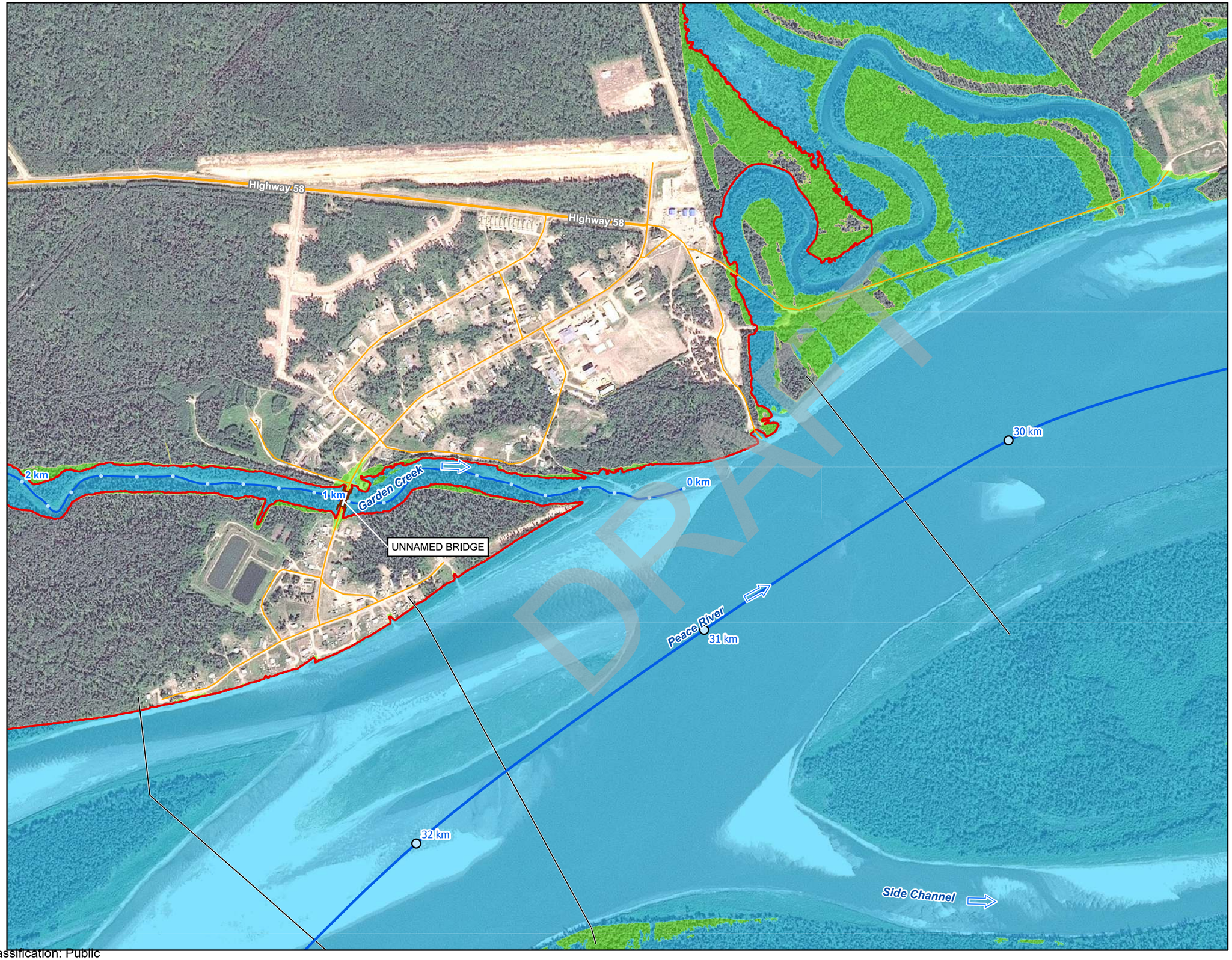
GARDEN RIVER FLOOD STUDY
ICE JAM FLOODWAY CRITERIA MAP

SHEET 1 OF 6

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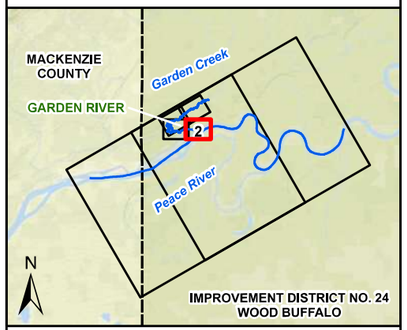
Classification: Public

SHEET 1



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- 1 KM RIVER STATION
- FLOW DIRECTION
- GARDEN CREEK BANKS
- 1D MODEL SECTIONS
- DEPTH >= 1 m
- 1:100 ICE JAM FLOOD EXTENT
- PROPOSED ICE JAM FLOODWAY LIMIT

SCALE - 1:10,000
0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

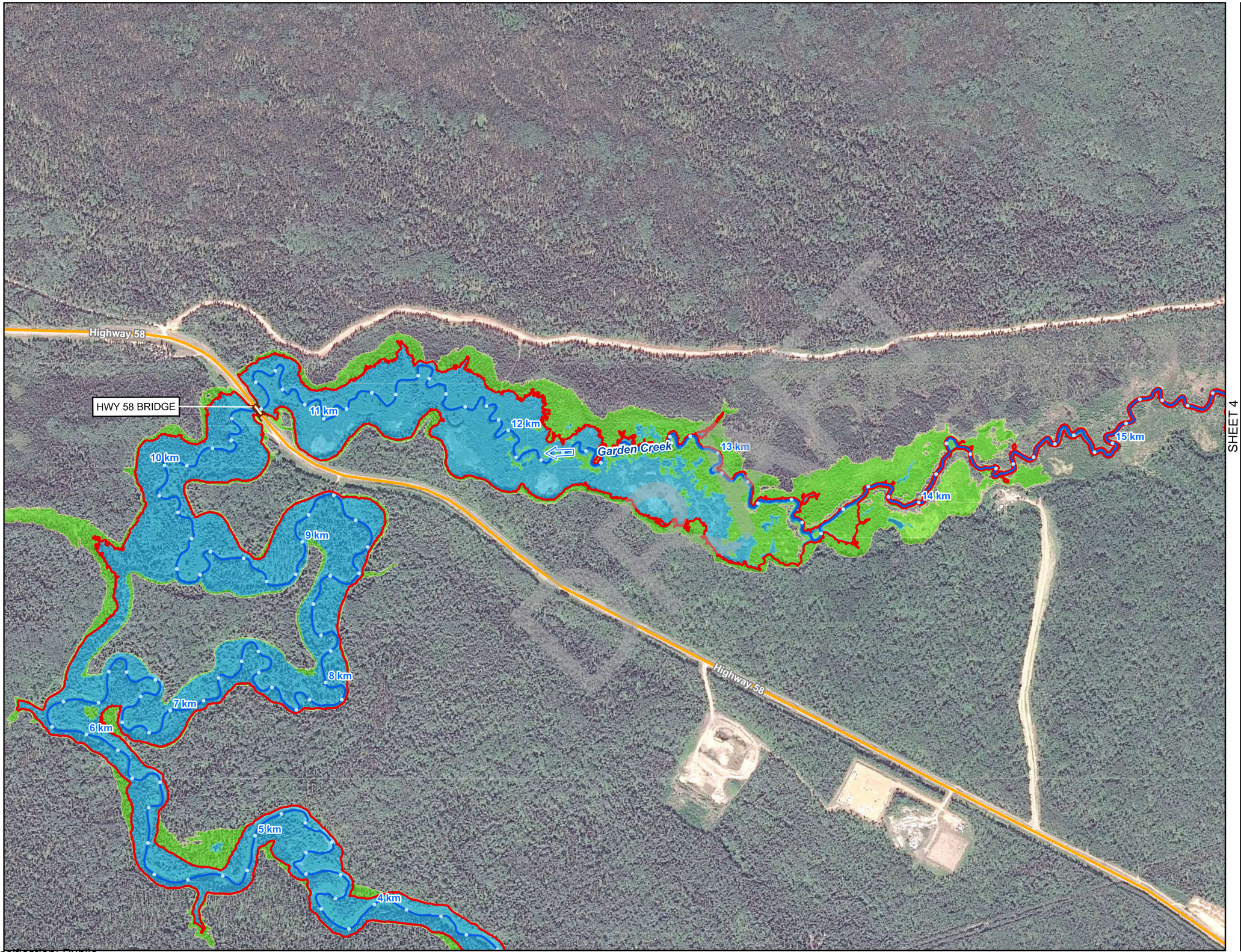
Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY
ICE JAM FLOODWAY CRITERIA MAP

SHEET 2 OF 6

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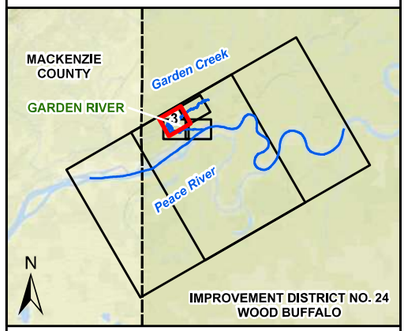
Classification: Public



SHEET 4

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- FLOW DIRECTION
- GARDEN CREEK BANKS
- 1D MODEL SECTIONS
- DEPTH >= 1 m
- 1:100 ICE JAM FLOOD EXTENT
- PROPOSED ICE JAM FLOODWAY LIMIT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

Coordinate System: NAD 1983 CSRS 3TM 114; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY
ICE JAM FLOODWAY CRITERIA MAP

SHEET 3 OF 6

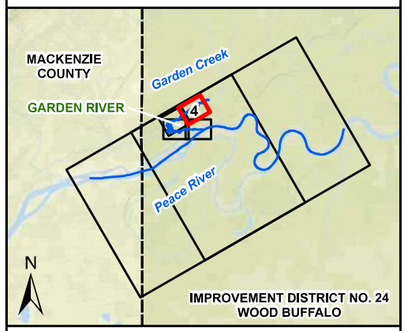
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SHEET 3



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 100 m RIVER STATION
- FLOW DIRECTION
- GARDEN CREEK BANKS
- 1D MODEL SECTIONS
- DEPTH >= 1 m
- 1:100 ICE JAM FLOOD EXTENT
- PROPOSED ICE JAM FLOODWAY LIMIT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

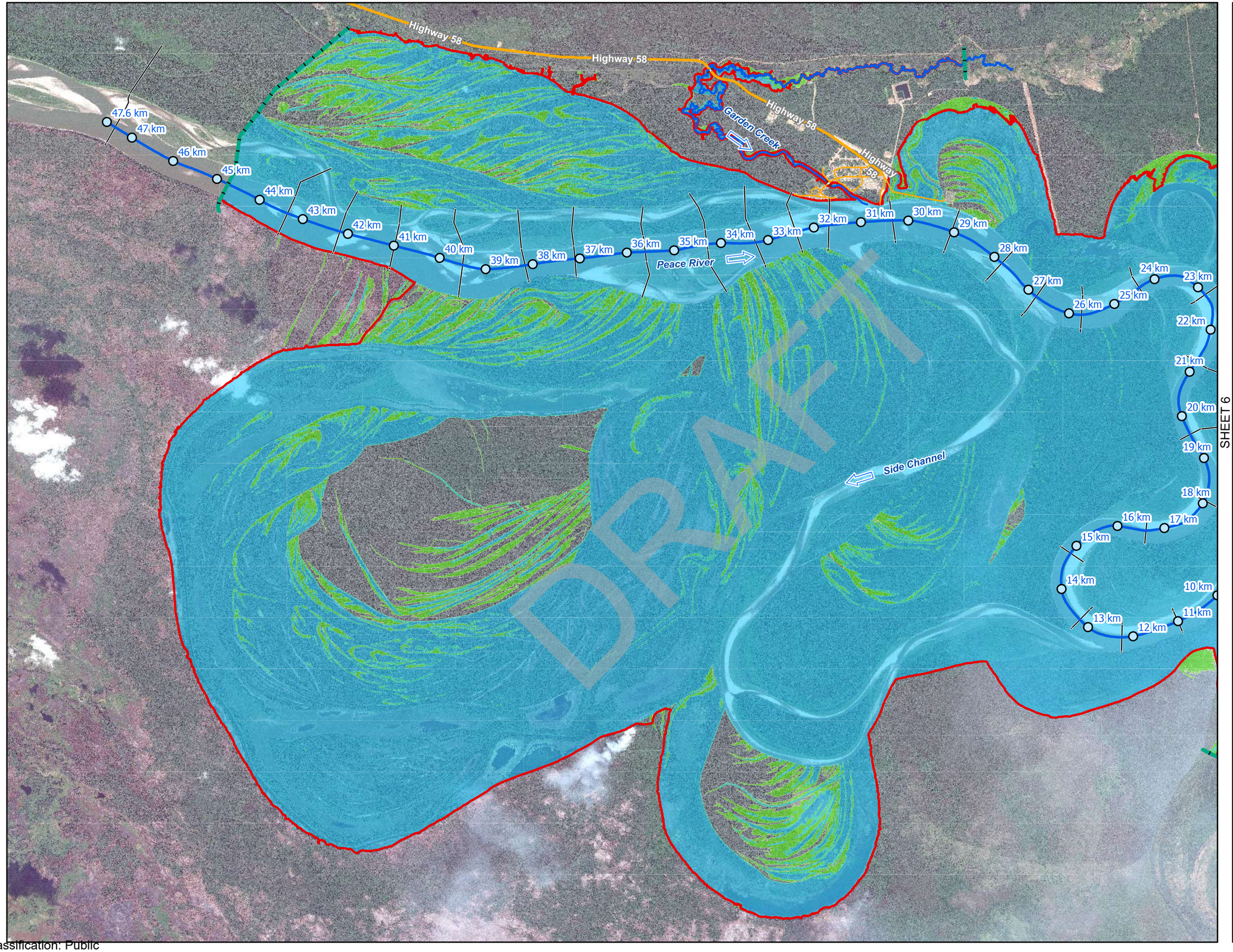
Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY
ICE JAM FLOODWAY CRITERIA MAP

SHEET 4 OF 6

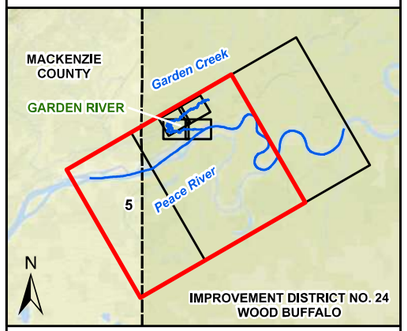
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Classification: Public



Alberta Canada

nhc



SHEET 6

- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- GARDEN CREEK BANKS
- 1D MODEL SECTIONS
- DEPTH >= 1 m
- 1:100 ICE JAM FLOOD EXTENT
- PROPOSED ICE JAM FLOODWAY LIMIT

SCALE - 1:75,000

0 0.5 1 1.5 2 2.5 3 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

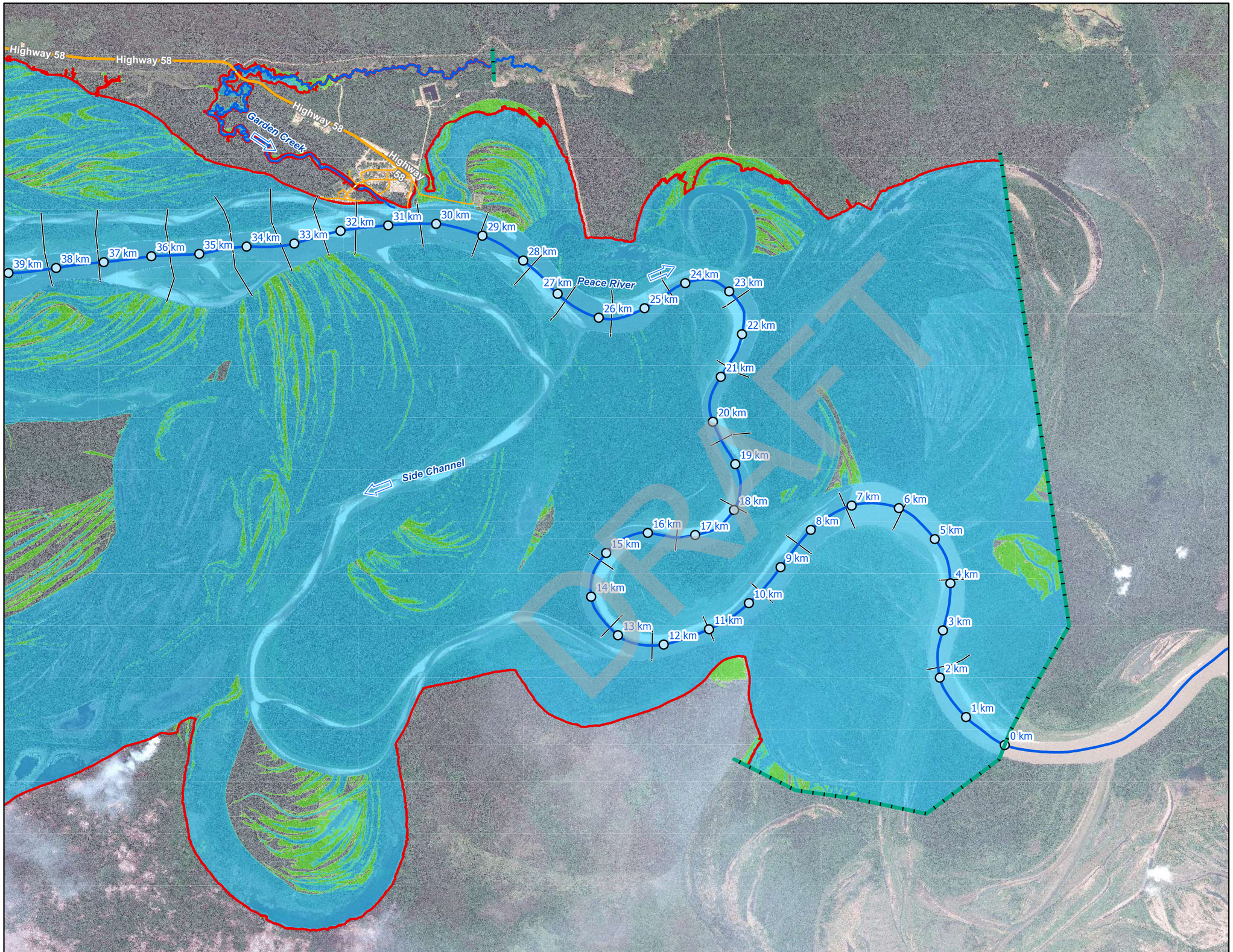
GARDEN RIVER FLOOD STUDY

ICE JAM FLOODWAY CRITERIA MAP

SHEET 5 OF 6

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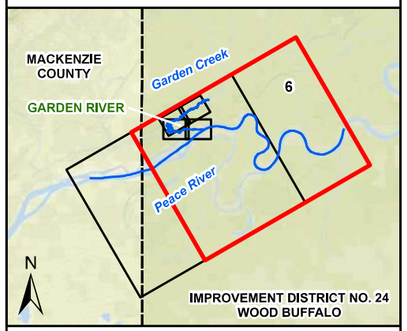
Classification: Public



SHEET 5

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRELINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- GARDEN CREEK BANKS
- 1D MODEL SECTIONS
- DEPTH >= 1 m
- 1:100 ICE JAM FLOOD EXTENT
- PROPOSED ICE JAM FLOODWAY LIMIT

SCALE - 1:75,000

0 0.5 1 1.5 2 2.5 3 Km

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY
ICE JAM FLOODWAY CRITERIA MAP

SHEET 6 OF 6

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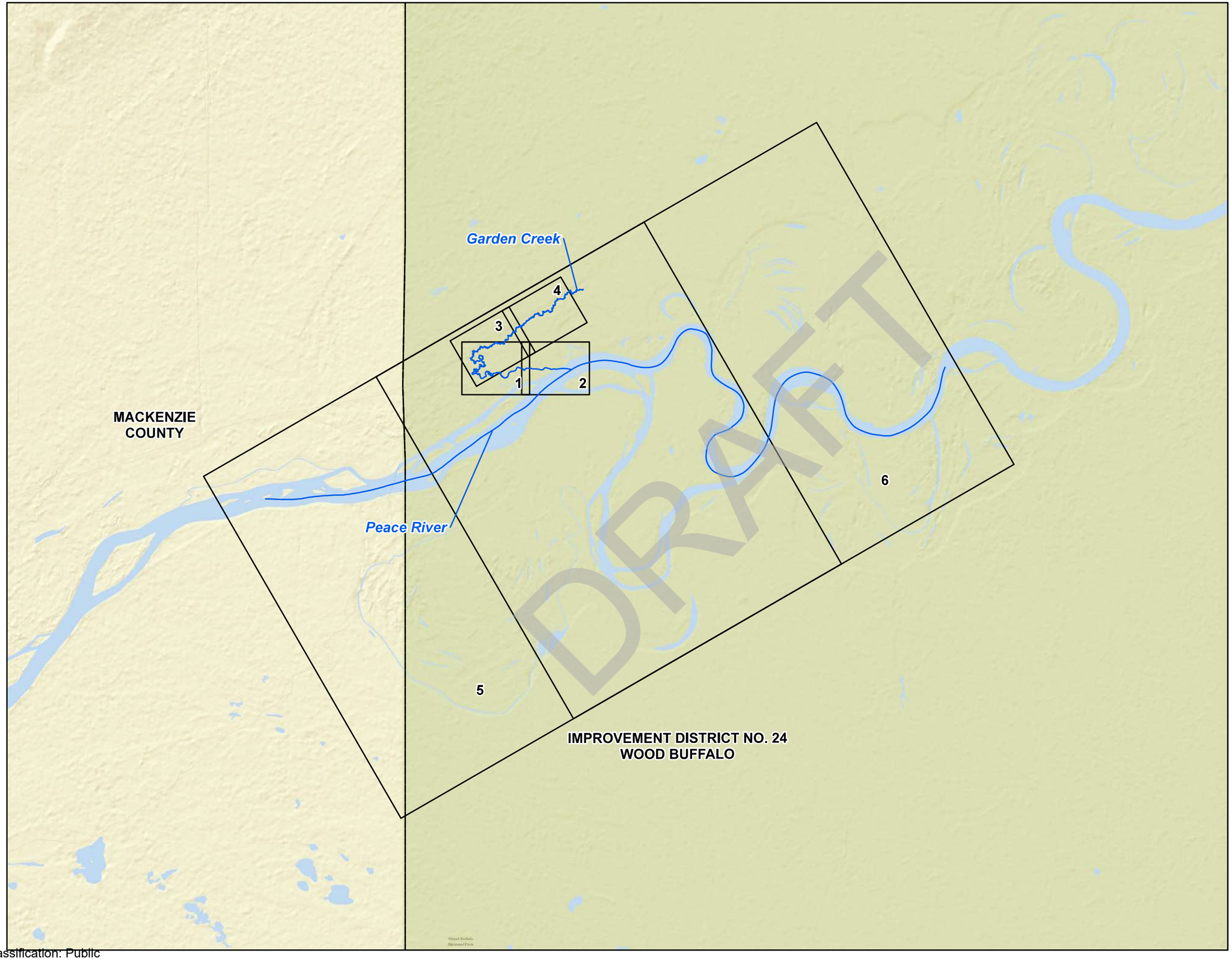
Classification: Public

APPENDIX L

FLOOD HAZARD MAP

DRAFT

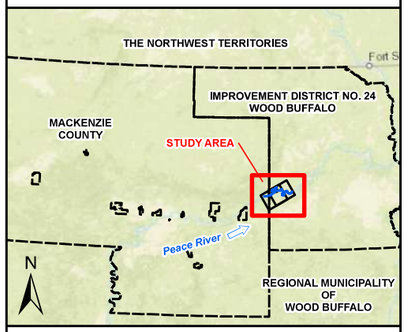
Classification: Public



DRAFT

Alberta Canada

nhc



- FLOW DIRECTION
- RIVER CENTRELINE
- MAP SHEETS
- COUNTY DISTRICT

SCALE - 1:180,000

0 2.5 5 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

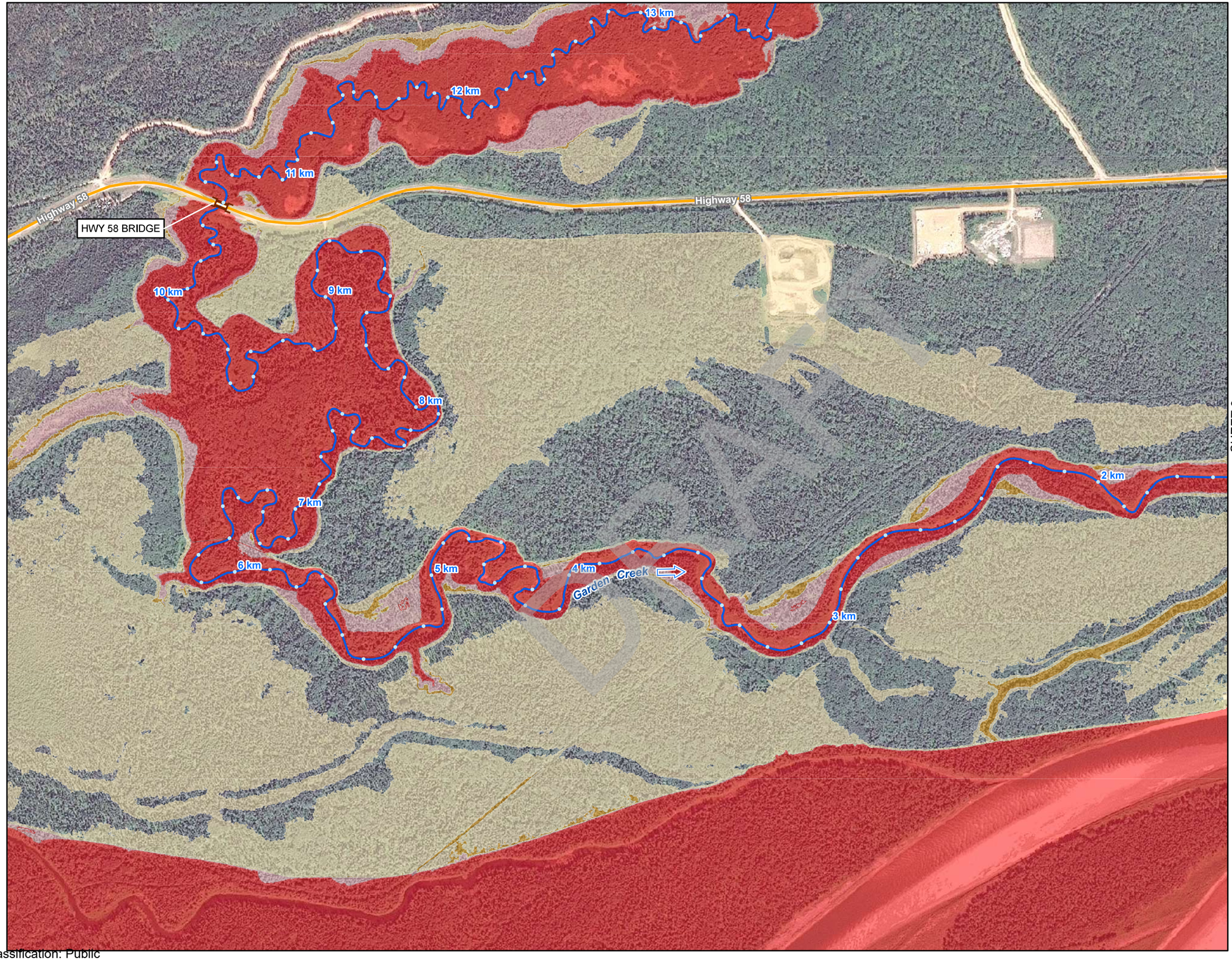
INDEX MAP

SHEET 1 OF 1

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Classification: Public

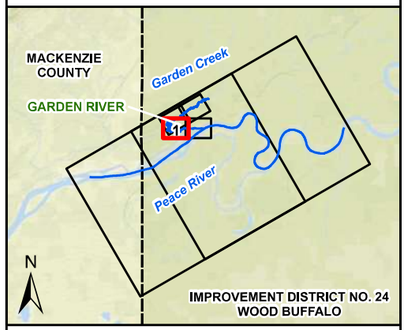
SHEET 3



SHEET 2

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRE LINE
- 100 m RIVER STATION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 1:200 FLOOD EXTENT
- 1:500 FLOOD EXTENT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

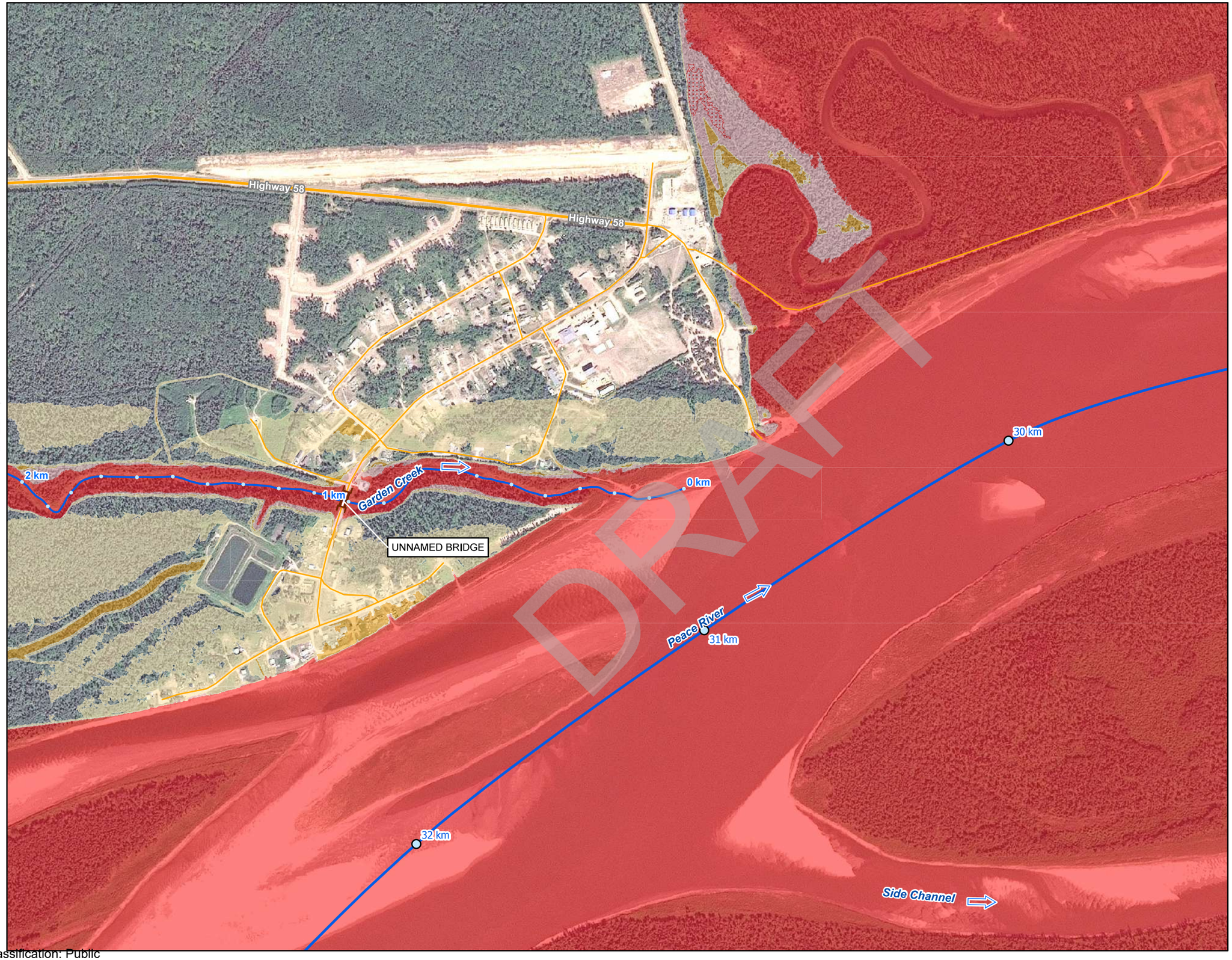
FLOOD HAZARD MAP

SHEET 1 OF 6

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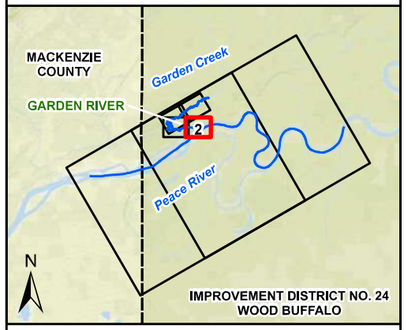
Classification: Public

SHEET 1



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRE LINE
- 100 m RIVER STATION
- 1 KM RIVER STATION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 1:200 FLOOD EXTENT
- 1:500 FLOOD EXTENT

SCALE - 1:10,000
0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

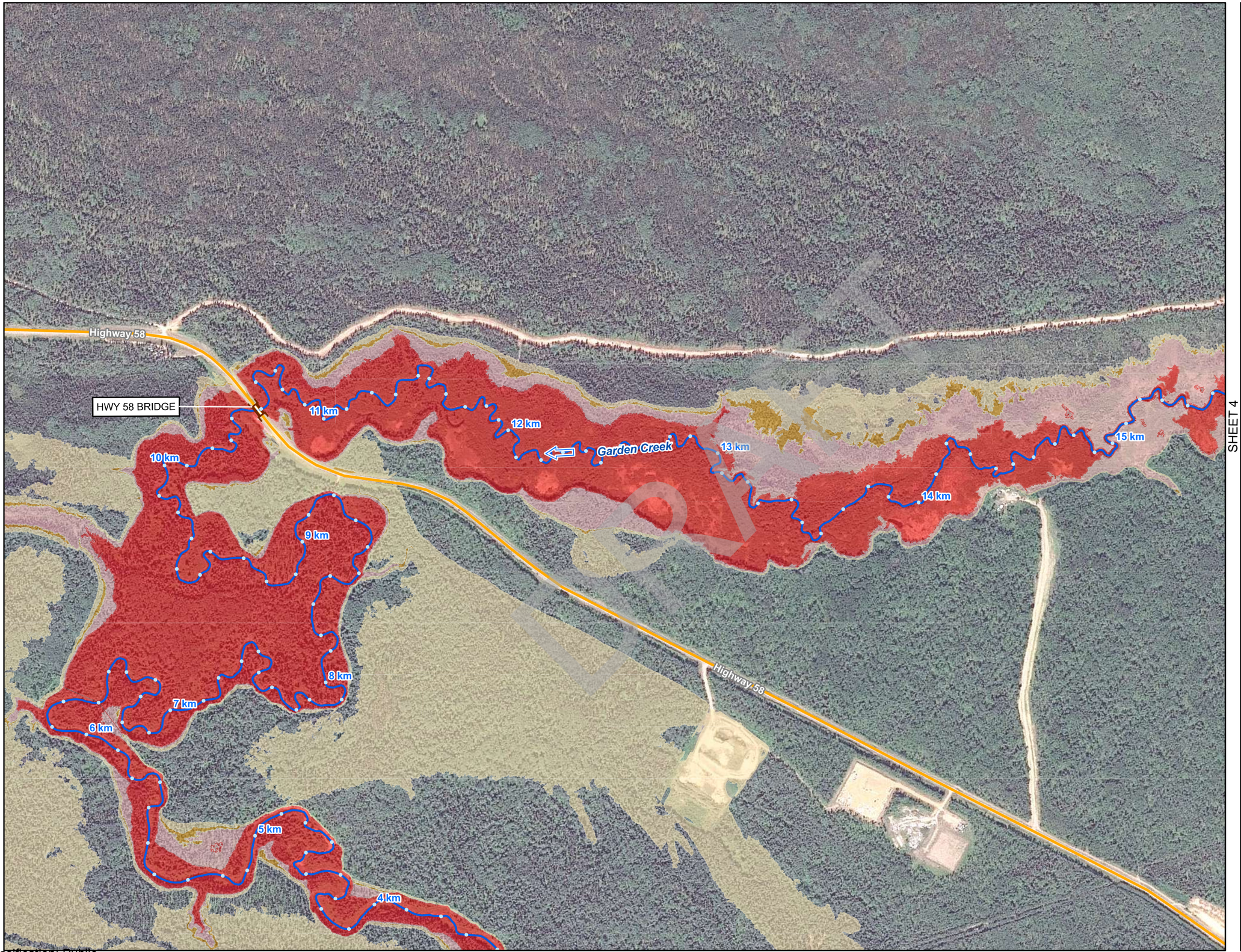
GARDEN RIVER FLOOD STUDY

FLOOD HAZARD MAP

SHEET 2 OF 6

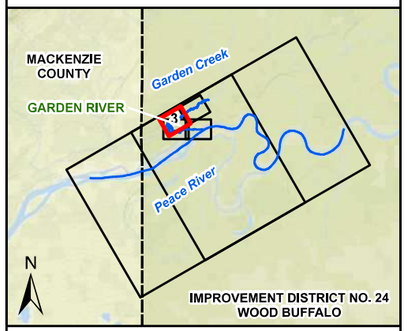
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Classification: Public



Alberta Canada

nhc



SHEET 4

- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRE LINE
- 100 m RIVER STATION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 1:200 FLOOD EXTENT
- 1:500 FLOOD EXTENT

SCALE - 1:10,000

0 0.1 0.1 0.2 0.3 0.3 0.4 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

FLOOD HAZARD MAP

SHEET 3 OF 6

J:\Y_P_Projects (Active)\1009251 Garden River Flood Study\90_GIS\700 Flood Hazard\1009251_Flood_Hazard_FINAL.aprx

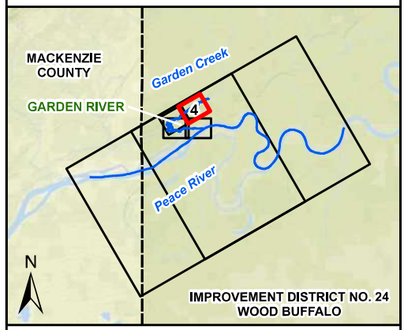
Classification: Public

SHEET 3

15 km
16 km
17 km
18 km
19 km
20 km
Garden Creek
Highway 58

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRE LINE
- 100 m RIVER STATION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 1:200 FLOOD EXTENT
- 1:500 FLOOD EXTENT

SCALE - 1:10,000
0 0.1 0.1 0.2 0.3 0.3 0.4 Km

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

FLOOD HAZARD MAP

SHEET 4 OF 6

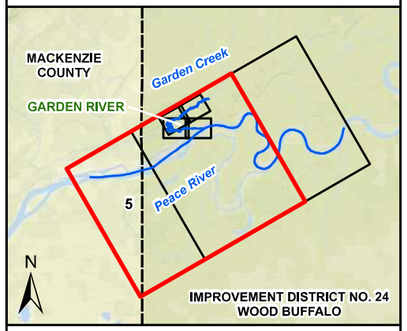
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Classification: Public



Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
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- STUDY BOUNDARY
- RIVER CENTRE LINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 1:200 FLOOD EXTENT
- 1:500 FLOOD EXTENT

SHEET 6

SCALE - 1:75,000

0 0.5 1 1.5 2 2.5 3 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

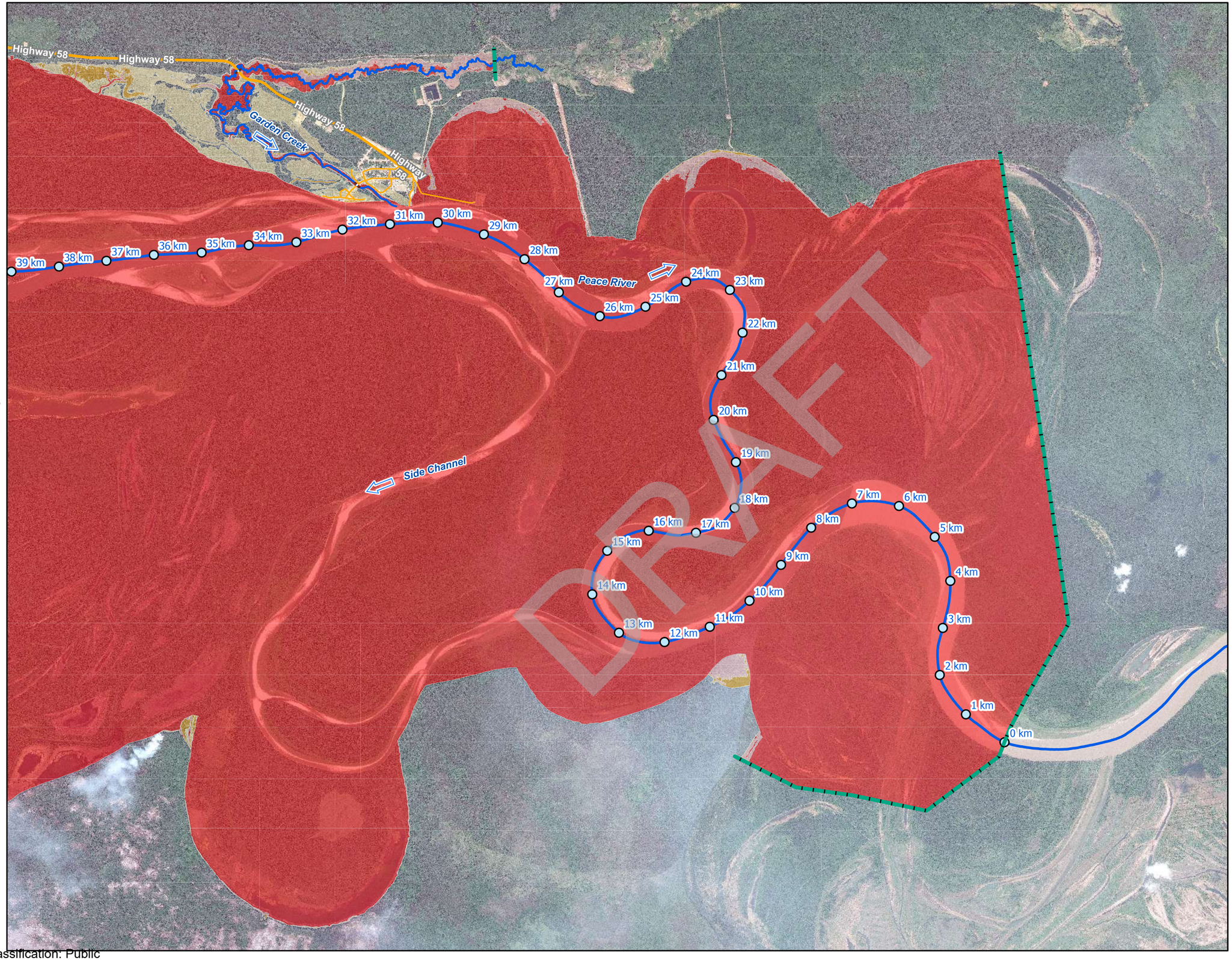
GARDEN RIVER FLOOD STUDY

FLOOD HAZARD MAP

SHEET 5 OF 6

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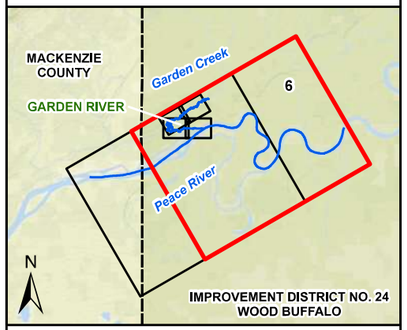
Classification: Public



SHEET 5

Alberta Canada

nhc



- MAJOR HIGHWAY
- LOCAL ROAD
- BRIDGE
- STUDY BOUNDARY
- RIVER CENTRE LINE
- 1 KM RIVER STATION
- FLOW DIRECTION
- FLOODWAY
- FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- 1:200 FLOOD EXTENT
- 1:500 FLOOD EXTENT

SCALE - 1:75,000

0 0.5 1 1.5 2 2.5 3 Km

N

Coordinate System: NAD 1983 CSRS 3TM 114;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
DJH	JY/DJH	RBA

Job Number	Date
1009251	8-MAY-2026

GARDEN RIVER FLOOD STUDY

FLOOD HAZARD MAP

SHEET 6 OF 6

J:\Y_P:_Projects (Active)\1009251 Garden River Flood Study\90_GIS\700 Flood Hazard\1009251_Flood_Hazard_FINAL.aprx

Classification: Public