Milk River (Photo taken 14 July 2022 during site visit by AEP and NHC)

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MILK RIVER FLOOD STUDY
FINAL REPORT

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March 29, 2022
Final Report

NHC Reference 1006666

Classification: Public

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EXECUTIVE SUMMARY

Alberta Environment and Parks retained Northwest Hydraulic Consultants Ltd. in June 2021 to complete a flood study at Milk River. The 7.2 km long study reach includes the town of Milk River and surrounding areas within Warner County. This study was completed under the Flood Hazard Identification Program (FHIP) with the intent to enhance public safety and reduce future flood damages within the Province of Alberta.

This report summarizes the work of all five components of the Milk River Flood Study – *Survey and Base Data Collection, Open Water Hydrology Assessment, Open Water Hydraulic Modelling, Open Water Flood Inundation Mapping, and Design Flood Hazard Mapping*.

The survey program was completed between 23 and 27 August 2021 when channel cross sections, hydraulic structures, and water levels were surveyed along the study reach. This information was used to develop the geometry required for the one-dimensional (1D) hydraulic model. A DTM, aerial imagery, and other base mapping features were also collected to support the model development and flood mapping.

Open water flood frequency estimates were developed as part of the open water hydrology component for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year flood scenarios. The flood frequency analysis was based on historical streamflow data collected by Water Survey Canada at the *Milk River at Milk River* gauging station (WSC Station 11AA005).

The open water hydraulic modelling component included the development of a calibrated hydraulic model that was used to calculate flood levels for the various flood frequency scenarios. The hydraulic model was calibrated by adjusting channel roughness so that the computed flood levels agreed with the observed 2002 and 2014 flood levels. The calibrated model also computed water levels that agreed well with water levels measured after the peak of the 2002 flood.

The computed water surface profiles were then used to determine the extent of inundation for each of the respective flood scenarios. The extent of inundation was then depicted on a series of open water flood inundation maps.

The design flood hazard mapping component provided a design flood hazard map – a key deliverable for this flood study. The design flood hazard map depicts the floodway and flood fringes (including high hazard areas) for the open water design flood. The supporting rationale for the flood hazard map is depicted on the open water floodway criteria map. The methods used to develop the flood hazard map follow the provincial Flood Hazard Identification Program guidelines, incorporating technical changes implemented in 2021 regarding how floodways are mapped in Alberta.

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CREDITS AND ACKNOWLEDGEMENTS

Northwest Hydraulic Consultants Ltd. would like to express appreciation to Alberta Environment and Parks for initiating this project, making extensive background information available, and providing the project team with valuable technical input throughout the project. Mr. James Choles managed and directed the Milk River Flood Study on behalf of Alberta Environment and Parks.

The following NHC personnel were part of the study team and participated in this study component:

- Dan Healy (Project Manager and Technical Lead) provided the overall direction of the hazard study and was the technical lead for this project.
- Makamum Mahmood (Senior Project Engineer) worked in open water hydrology assessment, hydraulic model development, flood history documentation, and floodway criteria determination. He is the primary author of this report.
- Jerry Yan (GIS Analyst) created the mapping products and developed the associated digital asset deliverables (including the inundation map libraries).
- Luke Kostyk and Ken Roy (Survey Technologists) collected and processed the field survey data.
- Gary Van der Vinne (Technical Reviewer) provided technical review and worked as the technical lead for the open water hydrology assessment.
- Sarah North (GIS Specialist) reviewed the mapping products and GIS deliverables.

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1 INTRODUCTION

1.1 Study Background

The Milk River Flood Study was initiated by Alberta Environment and Parks (AEP) to identify and assess flood hazards along a 7.2 km long reach of the Milk River within Warner County, including the town of Milk River. This study was facilitated under the Flood Hazard Identification Program (FHIP) with the intent to enhance public safety and reduce future flood damages within the Province of Alberta. Results from this study are intended to inform local land use planning decisions, flood mitigation projects, and emergency response planning.

To date, there have been no flood studies completed for this study reach – this is the first flood mapping study completed for the Milk River at Milk River.

This flood study is comprised of the five major study components listed below.

- Survey and Base Data Collection
- Open Water Hydrology Assessment
- Open Water Hydraulic Modelling
- Open Water Flood Inundation Mapping
- Design Flood Hazard Identification and Mapping

1.2 Study Objectives

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

- river cross section surveys;
- hydraulic structure data collection;
- survey and digital terrain model (DTM) data integration;
- documentation of flood history;
- open water hydrology assessment to provide flood frequency estimates;
- development of a calibrated, one-dimensional (1D) open water hydraulic model;
- simulation of open water floods of selected return periods, and creation of water surface profiles throughout the study reach;
- sensitivity analysis on selected modelling parameters;
- production of flood inundation maps for selected return periods;
- determination of floodway criteria and creation of design flood water surface profiles throughout the study reach; and
- production of floodway criteria maps and design flood hazard maps.

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1.3 Study Area and Reach

The Milk River Flood Study area is located approximately 100 km southeast of Lethbridge, Alberta. **Figure 1** shows the extent of the flood study area. The 7.2 km long flood study reach lies within the County of Warner and extends from the west boundary of NE-20-2-16-W4M downstream past the Town of Milk River to the south boundary of SE-22-2-16-W4M.

The Milk River originates in the Rocky Mountain foothills of northern Montana, flows northeast into Alberta, and then returns to the eastern part of Montana. The contributing drainage basin upstream of the Town of Milk River is approximately 2,720 km^2. A basin map is shown in **Figure 2.**

Flows in the Milk River have been regulated since 1917 by the St. Mary Diversion Canal. This canal diverts water from the St. Mary River in northwest Montana into the North Milk River, which joins the Milk River about 30 km upstream of the Town of Milk River. In a typical year, the canal increases the summer flows in the Milk River. Water in the Milk River is primarily used for irrigation, municipality supply and provides recreational opportunities.

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2 SURVEY AND BASE DATA COLLECTION

2.1 Procedure and Methodology

The survey program was completed between 23 and 27 August 2021. The objective of the survey program was to survey channel cross sections along the study reach to support development of a 1D hydraulic model. Before commencement of the work, a survey plan was submitted to and approved by AEP. A site visit was conducted prior to the survey on 13 and 14 July 2021 to inspect the study reach, identify highwater mark locations, and assess the overall condition of the river channel and floodplain.

Ground positioning for the survey was measured using Global Navigation Satellite Systems (GNSS) and Trimble R8 and R10 Real Time Kinetic (RTK) GNSS receivers. Milk River bathymetric surveys were conducted in areas generally deeper than 0.3 m using a CEESCOPE™ dual frequency digital echo sounder mounted on a boat to measure the water depth under the transducer. The position and elevation of the transducer were recorded with the RTK GNSS receiver, which was mounted directly above the transducer. River bed elevations were derived by subtracting sounding depths from transducer elevations. Elevations of shallower, wadable, areas in the river channel and on the ground along the river banks and in floodplains were directly measured with the RTK GNSS receiver attached to a survey rod. The surveyed cross sections included the river banks and extended into the floodplain, overlapping with the DTM provided by AEP.

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 operating conditions. Due to the pitch and roll of the boat when in motion, the expected accuracy of the boat-based survey is ±0.07 m. The accuracy of the collected survey data in both ground-based and boat-based surveys is within the expected accuracy mentioned in the proposal by AEP.

2.1.1 Coordinate System and Datum

Horizontal positions were referenced to the three-degree Transverse Mercator (3TM) projection with a central meridian of 111°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.

2.1.2 Control Network

A control point network was established from local Alberta Survey Control Monuments (ASCMs), and GNSS surveying to provide a spatial reference for the survey program. Four ASCMs and three NHC project survey control points were tied into the survey. A list of the control point coordinates is provided in **Table 1**.

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The coordinates for the three NHC control points were determined by running the GNSS receivers simultaneously in static mode for more than four hours at the control points to obtain CSRS precise point positioning (PPP) results for each control point and then post-processing baselines between control points using Trimble Business Center software to carry out a network adjustment. The adopted coordinates were obtained by constraining the survey to the NHC 1 control point base, which had the longest occupation time and most accurate CSRS-PPP results (the total horizontal error was 0.024 m (easting) and 0.034 m (northing), and total vertical error was 0.026 m). The horizontal and vertical errors in the other two control points after post-processing and adjustment to the reference CSRS-PPP values are summarized in **Table 2**. The largest horizontal error was 0.0008 m, and the largest vertical error was 0.0033 m.

Table 1 Control point summary

Point Name	Type	Easting (m)	Northing (m)	Elevation (m)
ASCM 783035	ASCM	-78502.593	5445754.823	1048.532
ASCM 49112	ASCM	-80192.167	5442512.641	1057.074
ASCM 11906	ASCM	-73693.437	5442422.780	1039.864
ASCM 935437	ASCM	-83432.060	5442583.896	1081.836
NHC 1	Project Control Point	-78937.046	5445684.414	1039.933
NHC 2	Project Control Point	-80129.429	5445816.595	1042.430
NHC 3	Project Control Point	-76893.028	5444173.386	1046.744

Table 2 Control network errors

Point Name	Easting (m)	Northing (m)	Elevation (m)
NHC 1 (constrained to)	N/A	N/A	N/A
NHC 2	0.0002	0.0005	0.0005
NHC 3	0.0006	0.0008	0.0033

A comparison between the surveyed elevations (after post-processing and adjustment) and published Alberta Survey Control Monuments (ASCM) elevations is provided in **Table 3**. The mean of the elevation residuals in **Table 3** is -0.04 m, which indicates good vertical agreement between the control network and local benchmarks.

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Table 3 Comparison between surveyed coordinates and published Alberta Survey Control Monument coordinates

Point Name	Residuals (Surveyed Minus Published)		
	Easting (m)	Northing (m)	Elevation (m)
ASCM 935437	-0.152	-0.047	-0.091
ASCM 783035	-0.700	-0.234	-0.026
ASCM 49112	-0.757	-0.288	-0.049
ASCM 11906	-0.775	-0.288	-0.008

2.2 Cross Sections

Cross section locations were selected to ensure adequate representation of the channel geometry in the hydraulic model. The locations of the cross sections are depicted on **Figure 3**. Cross sections are numbered sequentially from downstream to upstream.

A summary of the cross sections surveyed in the Milk River is provided in **Table 4**. A total of 54 cross sections were surveyed. Survey point data has been assembled and provided as part of the digital file submission.

Table 4 Cross section survey summary

Reach	Reach Length (km)	Number of Cross Sections	Average Spacing (m)	Maximum Spacing (m)	Minimum Spacing (m)
Milk River	7.7	54	146	244	12

The properties of cross sections surveyed on the Milk River are summarized in **Table 5**. The thalweg elevation is the minimum elevation surveyed at each cross section. The top of the bank (TOB) channel width was determined based on the survey data, an inspection of the LiDAR-derived DTM data, aerial imagery, and cross section profile.

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Table 5 Cross section properties

Cross Section	River Station (m)	Thalweg Elevation (m)	Channel Width (m)
XS-54	7720.10	1039.52	49.9
XS-53	7476.10	1038.98	36.0
XS-52	7286.60	1039.40	64.7
XS-51	7077.30	1037.65	32.5
XS-50	6922.70	1038.97	40.5
XS-49	6716.20	1038.73	63.2
XS-48	6485.00	1038.73	43.8
XS-47	6310.80	1038.06	63.9
XS-46	6124.80	1038.08	59.8
XS-45	6007.10	1037.38	72.6
XS-44	5836.30	1037.41	33.8
XS-43	5744.30	1037.32	57.3
XS-42	5623.20	1037.05	38.8
XS-41	5465.10	1036.99	53.9
XS-40	5263.60	1036.86	32.4
XS-39	5154.70	1036.07	30.1
XS-38	5045.10	1037.08	45.6
XS-37	4995.40	1037.06	52.6
XS-36	4983.40	1036.93	51.7
XS-35	4948.90	1036.81	57.6
XS-34	4928.90	1036.70	58.7
XS-33	4909.50	1036.98	55.2
XS-32	4889.30	1036.17	47.4
XS-31	4848.70	1036.26	40.4
XS-30	4818.80	1035.67	35.0
XS-29	4798.50	1036.71	37.2
XS-28	4743.90	1036.60	40.8
XS-27	4599.80	1036.25	35.0
XS-26	4395.50	1035.91	55.5
XS-25	4232.40	1035.47	39.2
XS-24	4056.20	1035.59	45.5
XS-23	3823.20	1035.46	44.2
XS-22	3648.20	1035.56	59.8
XS-21	3435.30	1035.13	46.0
XS-20	3241.50	1035.10	55.1
XS-19	2997.30	1034.08	55.8
XS-18	2821.60	1034.81	58.7
XS-17	2739.70	1033.92	39.1
XS-16	2625.90	1034.19	68.2
XS-15	2464.80	1033.24	42.0
XS-14	2316.20	1033.88	60.8
XS-13	2162.60	1033.80	52.6
XS-12	2031.60	1033.80	59.4
XS-11	1833.80	1032.89	43.9
XS-10	1625.00	1032.49	49.9
XS-09	1448.00	1032.40	43.2
XS-08	1215.50	1031.91	35.8
XS-07	989.40	1031.95	41.2
XS-06	819.00	1031.90	46.5
XS-05	580.30	1031.01	38.4
XS-04	443.00	1030.95	46.5
XS-03	216.60	1030.21	45.8
XS-02	104.90	1030.18	39.8
XS-01	0.00	1030.36	57.4

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2.3 Hydraulic Structures

Bridges are the only hydraulic structures along the study reach – no culverts, weirs, or other hydraulic structures were identified. The four bridges crossing the study reach are shown on **Figure** 3. and listed in **Table 6**. The table also includes the corresponding Bridge File (BF) numbers of Alberta Transportation (AT). Survey data collected for the bridges included: span length; deck width; top of curb or solid guardrail elevation; low chord elevation; number, width, type, shape, and location of piers; top of deck elevation; and photographs of the bridges.

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Table 6 Hydraulic structure summary

River Station (m)	AT Bridge File Number	Description	Structure Type
4989.40	BF81890	CP Railway Bridge	Bridge
4938.90	BF1426	Highway 4 South Bound Bridge	Bridge
4899.50	BF1426	Highway 4 North Bound Bridge	Bridge
4808.75	BF1426	Railway Street Bridge	Bridge

Survey data for these structures listed in the above table were assembled and provided in the digital file submission; details are provided in **Appendix A**

2.4 Flood Control Structures

The provincial FHIP Guidelines describe flood control structures as “walls constructed to prevent water from rivers or lakes from flooding surrounding lands. Often flood control structures are earthen berms but can also be constructed of concrete and other materials.”

Dedicated flood control structures, such as dikes, are structures constructed specifically to control flooding. These structures typically require regulatory approval prior to construction, receive routine inspection and maintenance, and are officially recognized by AEP and local authorities as flood management infrastructure.

Some road and railway embankments or berms may perform as flood barriers and affect the river hydraulics but may not be classified as dedicated flood control structures. These types of infrastructure are classified as non-dedicated flood control structures. Railroad embankments are typically assumed to be permeable and are not considered natural ground features or dedicated flood control structures.

Based on the guidelines and the information available from AEP and local authorities, NHC has confirmed that there are no dedicated flood control structures within the study reach.

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2.5 Other Survey Data

2.5.1 Discharge Measurement

A discharge measurement was conducted 50 m downstream of the WSC Station 11AA005 at XS-28, RS 4743.90 (refer to **Figure 3**) during the survey to provide a discharge corresponding to the water level profile collected during the survey. This information was used to support calibration of the hydraulic model. The measurement was taken on 26 August 2021 at around 15:30, using a boat mounted Sontek M9 RiverSurveyor Acoustic Doppler Current Profiler (ADCP), which can measure water depths ranging from 0.06 m to 40 m and provide an accuracy of ±0.25% in velocity measurement. The measured discharge is 14.641 m^3/s.

Preliminary real-time flow data for Milk River at Milk River (WSC Station 11AA005) are published by AEP. According to the AEP data, the Milk River discharge on the 26 August 2021 at around 15:30 is approximately 13.581 m^3/s, which is about 7% less than the measured discharge.

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2.5.2 Site Photographs

Appendix B provides annotated reach representative photographs obtained during the site inspection and survey program. The time and other metadata information are imbedded in the electronic image files.

2.6 Other Features

2.6.1 Water Survey of Canada Benchmarks

The WSC benchmark at the gauging station Milk River at Milk River (WSC Station 11AA005) was surveyed to tie historical water levels at the station to the study control network. **Table 7** lists the benchmark information and compares the published elevation to the surveyed elevation. The survey results indicate that the surveyed elevation is 0.009 m lower than the published gauge elevation, which indicates good vertical agreement between the published elevation and the surveyed elevation.

Table 7 Water Survey of Canada gauging station survey summary

Station Name (ID)	Cross Section	River Station (m)	Survey Type	Description	Elevation (m)		
					Published (from WSC Benchmark History)	NHC Survey	Difference
Milk River at Milk River (11AA005)	XS-29	4798.50	Benchmark	BM#79A643	1042.987	1042.978	0.009

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2.6.2 Aerial Imagery

Aerial imagery was acquired for AEP by OGL Engineering Ltd. on 17 June 2021. AEP provided fully processed orthophoto mosaics to NHC on 26 November 2021.

2.6.3 Design Drawings

Design drawings for bridges were obtained from Alberta Environment and Parks and Alberta Transportation for the following structures:

- CP Railway Bridge (BF81890)
- Highway 4 South and North Bound Bridge (BF1426)
- Railway Street Bridge (BF1426)

2.6.4 Hydrometric Gauging Station Information

Water level (stage) records, flow records, rating curves, and the station description for WSC Station 11AA005 – Milk River at Milk River were obtained to support hydraulic model calibration, and open

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water flood hydrology assessment. Information and data for other WSC hydrometric stations were also obtained for the open water hydrology assessment (**Appendix C**).

2.6.5 Base Mapping Features

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

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3 FLOOD HYDROLOGY

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

3.1 Flooding History

3.1.1 General Information

A description of local flood history has been prepared to provide context for the hydraulic model creation and calibration. This flood history documentation summarizes information related to both open water and ice jam related flooding that has been documented and observed. Representative photographs depicting historic open water and ice jam flood events are provided in **Figure 4** and **Figure 5** respectively.

3.1.2 Open Water Floods

3.1.2.1 Recent and Recorded Open Water Floods

Flows of Milk River at the Town of Milk River have been measured by the WSC at Station 11AA005 since 1909. The flow records are continuous over the entire period of record, except for 1909, 1910, and the first three months of 1911. Annual peak flows on the Milk River more commonly occur in spring (late March to May) due to snowmelt runoff with or without rainfall. Intense summer rainstorm events (June-July) may result in high annual peak flows as well.

The three largest recorded floods occurred at Milk River in 1986, 1975, and 2002. The largest flood on record is the 1986 flood, which occurred in late February. The peak instantaneous discharge for this flood event published by WSC is 279 m^3/s. The climate data in the Milk River Basin for the 1986 flood indicates a sudden temperature rise with rainfall, causing significant snowmelt runoff within the basin. The upstream, downstream, and surrounding WSC gauge data responded similarly to the same event, indicating that the peak flow at Milk River was caused by runoff rather than a local ice jam release upstream of the gauge. The 1986 station analysis provided by WSC for the Milk River at Milk River gauge states that the 26 February 1986 discharge measurement by WSC was within 4% of the WSC open water rating curve used at that time; therefore, even though there may have been some minor ice affects in the 1986 flood peak estimation, it can be characterized as an open water flood.

The 1975 and 2002 floods occurred in June and are believed to be due to summer rainstorms. The peak instantaneous discharges published by WSC for these two events are 260 m^3/s and 251 m^3/s, respectively.

The other noticeable open water floods with recorded peak instantaneous discharge over 200 m^3/s occurred in May 1927, June 1953, and June 1964. Another notable flood occurred in June 1948 with a peak instantaneous discharge of 174 m^3/s. Photos of the 1948 and 1964 floods are shown in **Figure 4**.

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3.1.2.2 Historic Open Water Floods

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

It appears that systematic information on floods prior to 1909 is not available. According to some residents at Milk River and as reported in the Hydrotechnical Summary from the AT bridge file for the Highway 4 bridge, an open water flood was observed in 1908. The flood most likely occurred in May or June, and the observed high water in 1908 was believed to be approximately 4 m above the low water (AT, 2011). No recorded or estimated peak flood discharge is available for the 1908 event.

3.1.3 Ice Jam Floods

Key evidence of historic ice jam flood events occurring on the Milk River were found in AT bridge files and corroborated during discussions with local residents. Evidence was found to indicate the occurrence of ice jam events in 1911, 1927, 1947, 1952, 1960, 1964, and 1965. The earliest documented ice jam flood found in this study was for the 1911 event which damaged the first-ever bridge constructed over the Milk River, within Canada. This historic bridge was located about 400 m downstream of the present Highway 4 bridge.

The highwater information found for these events documents highwater level in relation to the low water level: 2.3 to 2.7 m above the low water during the 1952 ice jam; 1.7 to 3.4 m above the low water during the 1964 ice jam; and 2.1 m above the low water during the 1965 ice jam. The elevation of the "low water level" is unknown and so it was not possible to attribute an accurate estimate of flood elevation for these events. Based on the WSC rating data, the likely range of low water level is between 1037.2 m and 1038.2 m. Adopting the middle of this range, that is 1037.7 m, the maximum water level from 1964 ice jam would be about 1041.1 m ±0.5 m.

AT bridge drawings for the new Highway 4 crossing denote a "HIGH ICE (FLOWING)" elevation of 1040.3 m and "HIGH ICE (TOP OF ICE JAM)" elevation of 1041.6 m. This top of ice jam level is consistent with the upper limit of the ice jam range establish in the previous paragraph. Design values are more typically upper limits rather than "most probable" values so the high ice elevation in 1964 was most likely about 1041.1 m. Depending on the thickness of the ice jam, a high top of ice jam level of 1041.1 m would have a corresponding highwater elevation some tens of centimeters below this elevation.

The study reach has a history of ice jam flooding and evidence suggests that highwater levels associated with the largest ice jam flood events are comparable to the 100-year open water design flood elevations determined herein.

3.2 Flood Frequency Analysis

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

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3.2.1 Flood Frequency Flow Estimates

Flood frequency estimates for the 2- to 1000-year floods were estimated for the Milk River at Milk River (WSC Station 11AA005). The adopted flood frequency estimates and corresponding 95% confidence limits are listed in **Table 8.**

Table 8 Adopted flood frequency estimates for Milk River at Milk River (WSC Station 11AA005)

Return Period (Years)	Annual Probability of Exceedance (%)	Peak Instantaneous Discharge (m^3/s)	
		Value	95% Confidence Limits
1000	0.1	397	364 - 439
750	0.13	383	351 - 422
500	0.2	361	331 - 398
350	0.29	343	315 - 378
200	0.5	313	288 - 345
100	1	277	255 - 304
75	1.3	262	241 - 287
50	2	240	221 - 263
35	2.9	221	204 - 242
20	5	190	176 - 208
10	10	152	141 - 166
5	20	113	104 - 124
2	50	59	49 - 68

3.2.2 Comparison with Previous Study

Flood frequency estimates for the Milk River at Milk River (WSC Station 11AA005) were determined in two previous studies conducted by Alberta Environment (AENV) in 2001 and 2013.

The current flood frequency estimates for the Milk River at Milk River (WSC Station 11AA005) are listed again in **Table 9** in comparison to the previous studies. The current flood frequency estimates are comparable with previous flood frequency estimates (AENV, 2001 and 2013).

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Table 9 Flood frequency discharge estimates for Milk River at Milk River (WSC Station 11AA005) and compared with previous studies

Return Period (Years)	Annual Probability of Exceedance (%)	Flood Frequency Discharge (m^3/s)		
		NHC (current study)	AENV (2001)	AENV (2013)
1000	0.1	397	428	404
750	0.13	383		
500	0.2	361	387	369
350	0.29	343		
200	0.5	313	332	321
100	1	277	291	284
75	1.3	262		
50	2	240	249	247
35	2.9	221		
20	5	190	194	196
10	10	152	153	157
5	20	113	111	116
2	50	59	57	59

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4 HYDRAULIC MODELLING

4.1 Available Data

The data available to develop and calibrate the hydraulic model are described below.

4.1.1 Digital Terrain Model

Bare-earth and full-feature digital terrain model (DTM) data sets were provided by AEP in October 2021. The data were derived from a LiDAR survey conducted on 21 April 2021. The bare-earth DTM was used to extend cross sections for the hydraulic model to cover overbank flow areas.

4.1.2 Existing Hydraulic Models

No existing model is available for the current study reach of Milk River.

4.1.3 Highwater Marks

A highwater mark (HWM) survey documents the highest water levels experienced along the river during the passage of a flood event. Typically, the observations are taken not long after the passage of the flood while evidence of the highest water level experienced at the HWM location remains apparent. The HWM survey data collected from the 2002 and 2014 floods were examined for this study.

Table 10 lists the HWM elevation values reported for the June 2002 and June 2014 floods and **Figure 6** depicts their locations along the river. The locations were initially plotted from approximate observation coordinates included within the HWM reports provided by AEP. These locations were further adjusted based on the available information specific to each HWM observation site (e.g. site photographs and/or remarks on their location with respect to prominent features, such as bridges or buildings). Each HWM location was then assigned a river station value representative of its location alongside the model channel centerline; that is, the streamwise distance from the downstream model boundary. NHC was unable to plot and locate three HWM locations from 2002 flood as they were referenced to an old bridge support that could not be clearly identified. At a few HWM locations the reported elevation values appeared suspiciously high or low in relation to the neighboring HWMs. It is plausible that the reported elevation value at these locations is in error or the streamwise location could not be accurately deduced from the information available in the HWM reporting – these locations were denoted as "suspect" in **Table 10**. In some instances, the location of the HWM along the river (river station) could not be deduced from the information provided in the HWM report; these cases are denoted in the table as "location unknown".

The corresponding peak discharge rates for these two HWM events (10 June 2002 and 20 June 2014) were obtained from the published peak instantaneous flows at the WSC Station 11AA005 (Milk River at Milk River).

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Table 10 Summary of highwater marks for 2002 and 2014 floods

Highwater Mark ID	Reported Location Description	River Station (m)	Discharge (m³/s)	HWM Elevation (m)	Remark
HWM-2002-MR-3	500 m west and 700 m south of Milk River Town	6,217.00	251	1041.685	
HWM-2002-MR-4	500 m u/s Milk River Town bridge in private yard	5,407.00		1041.087	
HWM-2002-MR-5a	Immediately d/s hwy bridge (right bank)	4,798.50		1040.748	Suspect
HWM-2002-MR-5b	Immediately u/s hwy bridge (right bank)	4,818.80		1040.663	
HWM-2002-MR-5c	15 m u/s hwy bridge (right bank)	4,828.00		1040.643	
HWM-2002-MR-5d	Immediately d/s railroad bridge (right bank)	4,836.00		1040.768	Suspect
HWM-2002-MR-5e	Immediately u/s railroad bridge (right bank)	4,853.00		1040.673	
HWM-2002-MR-5f	15 m u/s railroad bridge (right bank)	4,874.00		1040.668	
HWM-2002-MR-5g	Immediately d/s old bridge support (right bank)	N/A		1040.653	Location Unknown
HWM-2002-MR-5h	Immediately u/s old bridge support (right bank)	N/A		1040.718	Location Unknown
HWM-2002-MR-5i	30 m u/s old bridge support (right bank)	N/A		1040.683	Location Unknown
HWM-2002-MR-5j	Approx 100 m d/s hwy bridge and in line with brown house (right bank)	4,714.00		1040.493	
HWM-2002-MR-5k	Approx 150 m d/s hwy bridge and across from green shaft on left bank (right bank)	4,599.80		1040.168	
HWM-2002-MR-5l	Approx 200 m d/s hwy bridge and across from grey metal shed (right bank)	4,518.00		1040.003	
HWM-2002-MR-6	Kuhl's farm south and east of Milk River Town	3,670.00		1038.819	
HWM-2002-MR-7	1 km south of Milk River Town bridge, just south of "Welcome to Milk River" hoodoos entrance sign	3,184.00		1037.792	Suspect
HWM-2002-MR-8	1 mile east and 1 mile south of Milk River Town at end of RR162 to the west past house	174.00		1033.897	
2014-MR-3a	500 m west and 700 m south of Milk River Town	6,243.00	145	1041.031	
2014-MR-4.6,4.5,4.4-a	New highway 4 bridge at Milk River Town	4,889.30		1039.979	
2014-MR-4.6,4.5,4.4-b		4,905.00		1039.956	
2014-MR-4.6,4.5,4.4-c		4,920.00		1039.962	
2014-MR-4.6,4.5,4.4-d		4,921.00		1039.959	
2014-MR-4.6,4.5,4.4-e		4,957.00		1039.976	
2014-MR-4.6,4.5,4.4-f		4,968.00		1039.973	
2014-MR-5-a	Old (local) highway 4 bridge at Milk River Town	4,822.00		1039.824	
2014-MR-5-b		4,796.00		1039.772	

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4.1.4 2002 Post Flood Surveyed Water Levels

HWM elevations for 2002 flood along the Milk River study reach were collected on 12 June 2002 (two days after the peak of the 2002 flood and water levels had receded). During the HWM survey, AEP had also surveyed the river water levels at each HWM location. These surveyed water levels provided additional calibration data. The discharge reported at the gauge on the day of the HWM survey was 110 m^3/s, which is close to a 5-year event discharge.

Table 11 lists the surveyed water elevation values from 12 June 2002 survey.

Table 11 Summary of surveyed water levels on 12 June 2002

Highwater Mark ID	Reported Location Description	River Station	Discharge	Highwater Mark Elevation	Remark
		(m)	(m3/s)	(m)	
HWM-2002-MR-3	500 m west and 700 m south of Milk River Town	6,217.00		1040.72	
HWM-2002-MR-4	500 m u/s Milk River Town bridge in private yard	5,407.00		1040.077	
HWM-2002-MR-5a	Immediately d/s hwy bridge (right bank)	4,798.50		1039.443	
HWM-2002-MR-5b	Immediately u/s hwy bridge (right bank)	4,818.80		1039.488	
HWM-2002-MR-5c	15 m u/s hwy bridge (right bank)	4,828.00		1039.478	
HWM-2002-MR-5d	Immediately d/s railroad bridge (right bank)	4,836.00		1039.493	
HWM-2002-MR-5e	Immediately u/s railroad bridge (right bank)	4,853.00		1039.518	
HWM-2002-MR-5f	15 m u/s railroad bridge (right bank)	4,874.00		1039.523	
HWM-2002-MR-5g	Immediately d/s old bridge support (right bank)	N/A		1039.528	Location Unknown
HWM-2002-MR-5h	Immediately u/s old bridge support (right bank)	N/A		1039.553	Location Unknown
HWM-2002-MR-5i	30 m u/s old bridge support (right bank)	N/A	110	1039.558	Location Unknown
HWM-2002-MR-5j	Approx 100 m d/s hwy bridge and in line with brown house (right bank)	4,714.00		1039.318	
HWM-2002-MR-5k	Approx 150 m d/s hwy bridge and across from green shaft on left bank (right bank)	4,599.80		1039.268	
HWM-2002-MR-5l	Approx 200 m d/s hwy bridge and across from grey metal shed (right bank)	4,518.00		1038.843	
HWM-2002-MR-6	Kuhl's farm south and east of Milk River Town	3,670.00		1037.664	
HWM-2002-MR-7	1 km south of Milk River Town bridge, just south of "Welcome to Milk River" hoodoos entrance sign	3,184.00		1036.782	Suspect
HWM-2002-MR-8	1 mile east and 1 mile south of Milk River Town at end of RR162 to the west past house	174.00		1032.652	

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4.1.5 Gauge Data and Rating Curves

WSC Station 11AA005 (Milk River at Milk River), is the lone streamflow gauge located within the study reach. WSC has published discharge record for this gauge from 1909-2020 and the water level record from 2012-2020.

The relationship between stage (or height) and discharge at the gauging station is determined by WSC, based on recorded stage and direct discharge measurements. This relationship is represented by a curve fit through the observed data, commonly called a rating curve. New direct discharge measurements are continually added to the dataset, and the rating curve is adjusted periodically to fit the additional data. The rating curve relationship allows for discharge (streamflow) to be estimated from the recorded gauge height.

4.1.6 Aerial Flood Photography

Aerial flood photography was not found for this study reach. Ground photos of highwater events are referenced in the flood history section.

4.2 River and Valley Features

4.2.1 General Description

The Milk River is a tributary of the Missouri River, which originates in the Rocky Mountain foothills of northern Montana, flows northeast into Alberta, and then returns to the eastern part of Montana. The total length of the Milk River is approximately 1,173 km and the river basin covers an approximate area of 60,000 km^2 and extends into the Canadian provinces of Alberta and Saskatchewan and the US state of Montana. The Milk River drainage basin within Alberta is approximately 6,700 km^2, which is the smallest of Alberta's seven major river basins. The study area located within Warner County, Alberta including the town of Milk River.

4.2.2 Channel Characteristics

Milk River at Milk River flows through predominantly flat, undulating, and mainly cultivated terrain. The Milk River follows an irregular meander pattern with the occurrence of occasional islands, mid-channel bars, and point bars. The study reach-average channel slope is about 0.0012 m/m. The channel bed material consists of gravel with silty or sandy loam banks and the channel was frequently confined by valley walls composed of stony clay or sandstone (AMEC, 2008). Based on 2-year flow conditions, the average top width through the Milk River study reach is about 40 m and the mean depth is about 2 m.

4.2.3 Floodplain Characteristics

The floodplain of the Milk River is generally covered mostly in light vegetation with some cultivation.

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4.2.4 Anthropogenic Features

The town of Milk River is located within the study area. Four bridges cross the Milk River - details on these are provided in **Appendix A**. Milk River Visitors Center and 8 Flags Campground are also situated along the study reach.

4.3 Model Construction

4.3.1 Methodology

The U.S. Army Corps of Engineer's Hydrologic Engineering Center River Analysis System (HEC-RAS) computer program (Version 6.1, 2021) was used to calculate the flood levels along the study reach. The basic inputs required by HEC-RAS are a series of cross sections with known distances between sections, roughness coefficients for the channel, overbank areas for each cross section, inflow discharge at the upstream limits of each reach, and a prescribed water level at the downstream outflow boundary.

HEC-RAS can perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for a network of channels and hydraulic structures. For this study, a 1D model was constructed to calculate water surface profiles for steady-state gradually varied flow. The computational procedure for steady flow calculations is based on the solution of the 1D energy equation. Energy losses between river sections are calculated as friction losses (using Manning's equation) and as expansion / contraction losses. The momentum equation is used by the model for rapidly varied flow conditions, for hydraulics through bridges, and for evaluating water surface profiles at stream junctions.

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

- Flow is gradually varied and boundary friction losses between cross sections are estimated by Manning's equation using section-average parameters.
- Geometry is assumed to be fixed; thus potential changes in channel and floodplain geometry occurring during a flood are not accounted for.
- Each model cross section is apportioned into three separate conveyance components representing the main channel, left overbank, and right overbank, with a constant water level assumed across all three components.
- Flow is one-dimensional.

4.3.1.1 Geometric Layout

The approach followed to develop key components of the model geometric layout was:

- The channel centreline was defined along the middle of the main channel and was digitized using ArcGIS tools and visual referencing of the DTM and aerial imagery. A single continuous centreline was created to represent the model reach.
- Flow paths were created coincident with the river centerline and along the left and right floodplains, representing the length of the main channel, left overbank, and right overbank flow paths. Distances between cross sections were measured along flow path lines. The model

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requires these distances for estimating energy losses between cross sections within the main channel and the left and right overbank areas.

- Model cross section transects were digitized at each surveyed cross section as follows. First, a main channel portion was digitized across the main channel overtop of the surveyed channel and bank point data. Then, the main channel portion was extended left and right across the floodplain (overbank areas) and up the valley walls. The overbank portions were aligned perpendicular to the anticipated path of the floodplain flows and were projected far enough to extend beyond the 1000-year flood inundation extents. Cross section elevation values from the survey point data were projected onto the cross section lines using the RAS Mapper GIS toolset through a conflation process. Elevations in the overbank areas were determined by extracting elevation values from the underlying DTM along the cross section polylines.
- The location of the left and right banks (denoted as bank stations) were determined by inspection of the cross section geometry and examining DTM channel geometry. Bank stations demarcate the extents of the modelled left overbank, main channel, and modelled right overbank portions of cross sections.

4.3.1.2 Channel and Overbank Roughness

Manning's roughness values were used to simulate roughness in the modelled reaches. Manning's roughness is an empirical coefficient used to account for energy losses due a combination of factors including surface roughness and channel sinuosity. Manning's *roughness* also varies somewhat with discharge. For this study, the calibrated Manning's roughness values were held constant for the full range of design flood discharges. The Manning's roughness values adopted for the present study are discussed further in a subsequent section on model calibration.

4.3.1.3 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 0.10 for gradual transitions to 0.80 for abrupt transitions (Brunner, 2016).

4.3.1.4 Boundary Conditions

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 or a friction slope with which the water level will be calculated by HEC-RAS assuming a normal depth approximation.

4.3.1.5 Ineffective Flow Areas

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

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configuration of ineffective flow areas depends on site-specific circumstances and engineering judgement.

4.3.1.6 Geometric Database

All the HEC-RAS model geometry components are assembled into a geometric database and provided with the study's electronic deliverables. These components include point and vector features for survey data, model cross sections, flow paths, bank stations, and bridge locations. Components were developed using standard ArcGIS geospatial tools, and built-in HEC-RAS geometry tools (e.g. RASMapper). The contents of the geometric database and the model geometry development methodology are described in the following sections.

4.3.1.7 Cross Section Data

Appendix A contains elevation, survey, and other data derived from the NHC surveys for each model cross section. These cross section data sets included the combined DTM, topographic survey, and hydrographic survey data.

4.3.1.8 Bridges

The modelled reach includes four bridge crossings (**Table 6** and **Appendix A**). Each bridge structure's alignment and location were established in ArcGIS. Bridge cross sections include approach roadways and abutments in the left and right overbanks, bridge piers, and bridge deck high and low chord profiles. Approach roadway profiles are based on extracted DTM elevation data supplemented with data from bridge drawings. Abutment geometry, piers, and high and low chords were determined from surveyed data and/or drawings. Model bridge geometry was checked against design drawings, available AT bridge file records, and other information as available.

Key hydraulic structure design information incorporated into the model can be found in **Table 12** below. Any culverts in the study area that service local drainage only or were not relevant to the hydraulic model computations were not modelled.

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Table 12 Description of bridges included in the hydraulic model

Description	River Station (m)	Design Drawing /Info	Span (m)	Width (m)	No. of Piers	Pier Width (m)	Bridge Skew (°)	Minimum Elevation (m)	
								High Chord	Low Chord
CP Railway Bridge	4,989.40	Yes	84.9	5.5	1	1.8-2.4	none	1046.02	1042.60
Highway 4 SBL Bridge	4,938.90	Yes	81.8	13.6	1	1.4-1.8	none	1044.79	1042.83
Highway 4 NBL Bridge	4,899.50	Yes	81.8	13.6	1	1.4-1.8	none	1044.81	1042.82
Railway Street Bridge	4,808.75	Yes	63.7	15.9	2	0.9	none	1042.72	1041.16

For low flow conditions, the model was configured to use the highest energy solution of the energy, momentum, or Yarnell methods. The energy method was specified for conditions where a bridge is overtopped but this method was not invoked in the study.

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4.3.2 Model Calibration

4.3.2.1 Methodology

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

- Manning's roughness coefficient for the channel and floodplain.
- Friction slope associated with the downstream normal depth boundary condition.
- Ineffective flow areas.
- Expansion and contraction coefficients.

The primary calibration parameter is the channel Manning's roughness.

Roughness calibration challenges and limitations. These include:

- Accuracy of highwater mark elevations.
- Improper identification of highwater marks.
- Uncertainties in estimates of flood peak discharge.
- Presence of a hydraulic control between model cross sections.

Main channel Manning's roughness. The general calibration approach was to adjust Manning's *roughness* values such that computed water levels matched well with observed water levels for the adopted high flow calibration event (2002 and 2014 floods). The adjustments were made on a reach-

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averaged basis by visual comparison of computed and observed water levels. A single calibrated model representing both high and low flow conditions was created. Multiple models for different flow scenarios are generally not a desirable outcome for FHIP studies as they can present operational challenges to potential future users.

Overbank / floodplain roughness. Land cover type was used to help characterize roughness in the floodplain areas (model overbanks). Land cover type was based on ground observations aided by visual inspection of aerial imagery. The floodplain of the Milk River is generally covered mostly in light vegetation with some cultivation. A single manning's roughness value of 0.04 was selected as a representative roughness value for both left and right overbank areas along the entire study reach.

4.3.2.2 High Flow Calibration

The June 2002 and June 2014 flood events were used for high flow calibration. These are the largest flood events on record having well-documented highwater mark data. The HWMs for June 2002 flood event extends along the entire study reach, while the HWMs for June 2014 flood event are limited to the upper study reach. The 2002 estimated peak discharge was 251 m^3/s; this value exceeds the 50-year flood discharge but falls short of the 75-year discharge. The 2014 estimated peak discharge was 145 m^3/s; this value is just below the 10-year discharge.

The calibration results are illustrated by the comparison of the computed water surface elevations with the observed highwater mark elevations. **Figure 7** shows a comparison between the computed water surface profile and the observed highwater mark elevations for the June 2002 flood and **Figure 8** for June 2014 flood. **Table 13** tabulates a summary of the comparison. Excluding HWM locations deemed to be *suspect*, computed water levels were on average 0.03 m below observed 2002 flood event highwater marks and 0.02 m below observed 2014 flood event highwater marks. For the 2002 flood event, the average absolute difference between computed and observed highwater marks was 0.11 m; the largest positive difference was 0.18 m, and largest negative difference was -0.36 m. For the 2014 flood event, the average absolute difference between computed and observed highwater marks was 0.04 m; the largest positive difference was 0.05 m, and largest negative difference was -0.09 m.

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Table 13 High flow calibration results for Milk River

Highwater Mark ID	River Station (m)	Observed HWM Elevation (m)	Computed Elevation (m)	Computed minus Observed (m)	Remark
2002 Flood					
HWM-2002-MR-3	6,217.00	1041.69	1041.81	0.13	
HWM-2002-MR-4	5,407.00	1041.09	1041.27	0.18	
HWM-2002-MR-5a	4,798.50	1040.75	1040.52	-0.23	suspect
HWM-2002-MR-5b	4,818.80	1040.66	1040.56	-0.10	
HWM-2002-MR-5c	4,828.00	1040.64	1040.56	-0.08	
HWM-2002-MR-5d	4,836.00	1040.77	1040.57	-0.20	suspect
HWM-2002-MR-5e	4,853.00	1040.67	1040.59	-0.08	
HWM-2002-MR-5f	4,874.00	1040.67	1040.68	0.01	
HWM-2002-MR-5j	4,714.00	1040.49	1040.41	-0.08	
HWM-2002-MR-5k	4,599.80	1040.17	1040.19	0.02	
HWM-2002-MR-5l	4,518.00	1040.00	1040.13	0.12	
HWM-2002-MR-6	3,670.00	1038.82	1038.76	-0.06	
HWM-2002-MR-7	3,184.00	1037.79	1038.06	0.27	suspect
HWM-2002-MR-8	174.00	1033.90	1033.54	-0.36	
2014 Flood					
2014-MR-3a	6,243.00	1041.03	1041.08	0.05	
2014-MR-4.6,4.5,4.4-a	4,889.30	1039.98	1039.89	-0.09	
2014-MR-4.6,4.5,4.4-b	4,905.00	1039.96	1039.94	-0.02	
2014-MR-4.6,4.5,4.4-c	4,920.00	1039.96	1039.96	-0.01	
2014-MR-4.6,4.5,4.4-d	4,921.00	1039.96	1039.96	0.00	
2014-MR-4.6,4.5,4.4-e	4,957.00	1039.98	1039.99	0.02	
2014-MR-4.6,4.5,4.4-f	4,968.00	1039.97	1040.00	0.03	
2014-MR-5-a	4,822.00	1039.82	1039.75	-0.07	
2014-MR-5-b	4,796.00	1039.77	1039.71	-0.06	

Notes:

1. "suspect" denotes HWM observations that are likely to be in error in elevation or location.

A rating curve computed using the high flow calibration was compared to the published rating curves for the WSC gauge for Milk River at Milk River (WSC Station 11AA005). The computed curve compared well to the published curves (**Figure 9**) for the higher flow events. The computed curve follows the most recent projected rating curve (2019-2021) at both the 2002 and 1986 flood. Note that, both the computed and published rating curves underestimates the water level measurements for 2002 and 1986 flood.

The computed rating curve underpredicts the water levels over the range of lower discharges (up to about the 2-year flood) but performs very well over the range of higher discharges (5-year flood and larger). Closer examination of the available survey data, aerial imagery, and DTM suggested that there may be a channel control downstream of the bridges affecting these lower flows, causing the model to

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underpredict the lower end of the curve. At high flows the channel control is drowned out and the model well approximates the rating curve. The presence of a possible channel control was tested by blocking the lower portion of the cross section at the presumed location of the channel control (~400 m downstream of Railway St. Bridge) at cross section XS-26. The results of this test condition are depicted by the dashed red line in **Figure 9** . The test provides results that agree well with the rating curve at low flows without significant departure from the curve at high flows. This was an important test since it suggested that the departure from the rating curve at low flows could more likely be attributed to a local control than to a depth-varying roughness. A single roughness value was adopted for the full range of flow. Since the model was only developed for the purpose of simulating high flow conditions, the model geometry relied solely on the surveyed data and did not explicitly include the channel control. If a low flow simulation is required, then the model should be modified to include the channel control.

4.3.2.3 Comparison between Computed and Observed 12 June 2002 Surveyed Water Levels – High Flow Condition

The calibrated model was validated by using it to compute water levels along the reach corresponding to conditions observed on 12 June 2002. The model was applied using the WSC discharge reported for the day of the survey (110 m^3/s). **Figure 10** shows a comparison between the computed water surface profile and the observed water levels for the 12 June 2002 river survey. **Table 14** tabulates a summary of the comparison. Excluding HWM locations deemed to be *suspect*, computed water levels were on average 0.06 m below observed water levels. The average absolute difference between computed and observed water level was 0.10 m; the largest positive difference was 0.17 m, and largest negative difference was -0.23 m. The 12 June 2002 water levels are representative of a high flow condition and the calibrated model simulates this water levels well, so the model is representative of high flow conditions over the entire reach.

Table 14 Validation results for Milk River based on 12 June 2002 surveyed water levels

River Station (m)	Observed HWM Elevation (m)	Computed Elevation (m)	Computed minus Observed (m)	Remark
6,217.00	1040.72	1040.71	-0.01	
5,407.00	1040.08	1040.08	0.00	
4,798.50	1039.44	1039.33	-0.11	
4,818.80	1039.49	1039.37	-0.12	
4,828.00	1039.48	1039.37	-0.11	
4,836.00	1039.49	1039.37	-0.12	
4,853.00	1039.52	1039.38	-0.14	
4,874.00	1039.52	1039.44	-0.08	
4,714.00	1039.32	1039.22	-0.10	
4,599.80	1039.27	1039.04	-0.23	
4,518.00	1038.84	1038.95	0.10	
3,670.00	1037.66	1037.84	0.17	
3,184.00	1036.78	1037.20	0.42	suspect
174.00	1032.65	1032.63	-0.02	

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4.3.2.4 Comparison between Computed and Observed 24-26 August 2021 Surveyed Water Levels – Low Flow Conditions

The calibrated model was used to compute water levels corresponding to conditions observed over the duration of the 2021 cross sections survey (24-26 August) which are representative of a low flow condition. This comparison assesses the suitability of the Manning's roughness values calibrated for high flows for simulating low flows. **Table 15** summarizes the published daily discharge over the duration of the survey at Milk River at Milk River (WSC Station 11AA005).

Table 15 Published daily discharges during 2021 cross section survey – Milk River at Milk River (11AA005)

Cross Sections	River Stations (m)	Survey Date	Daily Discharge (m^3/s)
XS-54 to XS-37	7,720.10 to 4,995.40	25 August 2021	13.4
XS-36 to XS-29	4,983.40 to 4,798.50	24 August 2021	13.3
XS-28 to XS-21	4,743.90 to 3,435.30	25 August 2021	13.4
XS-20 to XS-01	3,241.50 to 0.00	26 August 2021	13.7

The calibrated model was then tested under three flow conditions corresponding to the daily flows listed in **Table 15**. **Figure 11** plots the comparison of computed water surface profiles for the three flow conditions and 2021 surveyed water levels at each cross section. Visual comparison of computed and surveyed water levels indicates that the adopted high flow Manning's roughness value appears to provide a reasonable simulation for low flows except in the area upstream of the potential low flow control discussed in Section 4.3.2.2.

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4.3.3 Model Parameters and Options

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

4.3.3.1 Manning's Roughness Coefficient

Computations in HEC-RAS are based on quantifying the friction loss between cross sections using Manning's roughness equation. The Manning's roughness coefficient is a parameter that accounts for losses attributed to river bottom material size and shape, floodplain conditions, and variations in the general river planform. A description of the channel and floodplain roughness values adopted in the model follows.

Channel Roughness

Channel roughness was calibrated along the study reach for the high flow events. A single reach-averaged channel roughness value of n = 0.03 was adopted.

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Overbank Roughness

For overbank floodplain areas and islands, a Manning's roughness of *n* = 0.04 was adopted based on the land use type (Arcement and Schneider, 1989 and Chow, 1959).

4.3.3.2 Expansion and Contraction Coefficients

To account for the effect of flow contraction and expansion losses on the energy balance between successive cross sections, HEC-RAS multiplies the absolute difference in velocity head by a coefficient. The default values of 0.1 and 0.3 (for expansion and contraction coefficients) were utilized throughout the entire model domain, excepting cross sections located at the bridge crossings. At these cross sections, expansion and contraction coefficients were increased to 0.3 and 0.5, respectively.

4.3.3.3 Boundary Conditions

At the downstream boundary, a normal depth water level approximation was assigned as the boundary condition. The slope used for calculating normal depth was set to 0.0010 m/m. This value approximates the slope of the energy grade line near the downstream boundary.

4.3.3.4 Weir Coefficient

For this study, even the 1000-year flood does not overtop any of the bridge decks. Therefore, flow overtopping road, rail, or similar embankments crossing the flow path was not simulated, so the broad crested weir coefficient had no effect on the study results.

4.3.3.5 Ineffective Flow Areas

Ineffective flow areas were specified at cross sections in the HEC-RAS model based on a review of local terrain and floodplain features at and between cross sections. Ineffective flow areas can be specified within portions of cross sections where the downstream velocity is expected to be close to or equal to zero (Brunner, 2016).

In the model, permanent and non-permanent ineffective flow areas may be specified. Permanent ineffective flow areas are ineffective at all water surface elevations, whereas temporary ineffective flow areas become effective above a defined elevation. For this study, only permanent ineffective flow areas were specified. Non-permanent areas often produce the undesirable result of computed high flood magnitude water level profiles dipping below computed lower flood magnitude water level profiles.

Permanent ineffective flow areas were used to account for flow patterns influenced by nearby bridge abutments and roadway embankments crossing the floodplain. These types of obstructions tend to direct flows towards the bridge opening. Several site-specific factors were taken into account when configuring ineffective flow areas at bridges in the study area, including distance from the cross section to the bridge, terrain features, and bridge geometry.

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4.3.3.6 Flow Splits and Islands

There are two small islands within the study reach but the study reach was adequately represented without simulating flow splits around these islands. Where cross sections intersected these islands, the HEC-RAS model assumed equal water levels on both sides of the islands based on the composite channel conveyance properties and computed energy losses. The validity of this assumption increases as flood magnitudes increase beyond the point where the island is inundated.

Diversions may include avulsion channels or flow paths along a portion of the study reach that reduce total main channel discharge there. There were no such diversions encountered within the study area; all flood flows were confined to the cross sections modelled along the study reach.

4.3.4 Flood Frequency Profiles

The calibrated hydraulic model was used to generate flood frequency profiles for the thirteen open water floods of varying magnitude listed in **Table 8. Table 16** lists the computed flood frequency water levels at each cross section. **Figure 12** displays these results.

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Table 16 Computed flood frequency water levels

Cross Section	River Station (m)	Flood Return Period and Discharge (m³/s)												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		59	113	152	190	221	240	262	277	313	343	361	383	397
		Water Surface Elevation (m)												
XS-56	8108.50	1041.87	1042.61	1042.93	1043.19	1043.37	1043.47	1043.57	1043.65	1043.78	1043.85	1043.89	1043.93	1043.96
XS-55	7888.90	1041.68	1042.38	1042.70	1042.95	1043.13	1043.23	1043.32	1043.39	1043.51	1043.60	1043.64	1043.68	1043.71
XS-54	7720.10	1041.54	1042.21	1042.54	1042.79	1042.98	1043.07	1043.18	1043.28	1043.41	1043.50	1043.54	1043.58	1043.61
XS-53	7476.10	1041.34	1041.95	1042.28	1042.55	1042.75	1042.85	1042.98	1043.06	1043.25	1043.37	1043.41	1043.46	1043.49
XS-52	7286.60	1041.16	1041.80	1042.16	1042.45	1042.66	1042.77	1042.90	1042.99	1043.17	1043.30	1043.34	1043.39	1043.41
XS-51	7077.30	1040.85	1041.46	1041.79	1042.07	1042.28	1042.40	1042.54	1042.64	1042.86	1043.01	1043.09	1043.17	1043.21
XS-50	6922.70	1040.71	1041.30	1041.63	1041.89	1042.08	1042.19	1042.30	1042.38	1042.53	1042.67	1042.74	1042.84	1042.91
XS-49	6716.20	1040.54	1041.17	1041.51	1041.78	1041.98	1042.09	1042.21	1042.30	1042.46	1042.60	1042.68	1042.77	1042.83
XS-48	6485.00	1040.27	1040.92	1041.26	1041.51	1041.70	1041.81	1041.94	1042.02	1042.22	1042.39	1042.48	1042.59	1042.66
XS-47	6310.80	1040.09	1040.80	1041.17	1041.46	1041.67	1041.79	1041.92	1042.01	1042.21	1042.37	1042.46	1042.56	1042.63
XS-46	6124.80	1039.92	1040.70	1041.09	1041.38	1041.59	1041.71	1041.84	1041.93	1042.15	1042.32	1042.42	1042.53	1042.60
XS-45	6007.10	1039.83	1040.61	1041.00	1041.29	1041.50	1041.62	1041.75	1041.84	1042.04	1042.21	1042.30	1042.41	1042.48
XS-44	5836.30	1039.69	1040.43	1040.79	1041.09	1041.30	1041.42	1041.55	1041.64	1041.85	1042.02	1042.11	1042.22	1042.29
XS-43	5744.30	1039.66	1040.43	1040.80	1041.10	1041.31	1041.43	1041.56	1041.65	1041.86	1042.03	1042.12	1042.22	1042.29
XS-42	5623.20	1039.54	1040.29	1040.67	1040.99	1041.21	1041.34	1041.47	1041.56	1041.78	1041.96	1042.05	1042.16	1042.23
XS-41	5465.10	1039.41	1040.19	1040.59	1040.92	1041.14	1041.27	1041.40	1041.49	1041.71	1041.89	1041.98	1042.09	1042.16
XS-40	5263.60	1039.19	1039.93	1040.34	1040.68	1040.90	1041.03	1041.16	1041.24	1041.45	1041.58	1041.66	1041.77	1041.84
XS-39	5154.70	1039.07	1039.78	1040.20	1040.53	1040.77	1040.91	1041.06	1041.16	1041.37	1041.55	1041.65	1041.77	1041.85
XS-38	5045.10	1039.01	1039.75	1040.16	1040.50	1040.75	1040.88	1041.03	1041.13	1041.34	1041.50	1041.60	1041.71	1041.79
XS-37	4995.40	1038.96	1039.71	1040.14	1040.47	1040.71	1040.85	1040.99	1041.08	1041.28	1041.44	1041.53	1041.63	1041.70
XS-36	4983.40	1038.90	1039.66	1040.08	1040.41	1040.65	1040.78	1040.92	1041.01	1041.21	1041.37	1041.46	1041.56	1041.63
XS-35	4948.90	1038.87	1039.63	1040.05	1040.39	1040.63	1040.76	1040.90	1040.99	1041.20	1041.35	1041.44	1041.54	1041.61
XS-34	4928.90	1038.83	1039.60	1040.03	1040.36	1040.60	1040.74	1040.88	1040.97	1041.17	1041.32	1041.41	1041.51	1041.59
XS-33	4909.50	1038.81	1039.59	1040.01	1040.35	1040.59	1040.73	1040.87	1040.96	1041.16	1041.31	1041.40	1041.50	1041.57
XS-32	4889.30	1038.73	1039.53	1039.96	1040.29	1040.53	1040.66	1040.80	1040.89	1041.09	1041.24	1041.32	1041.42	1041.49
XS-31	4848.70	1038.65	1039.41	1039.82	1040.15	1040.38	1040.50	1040.63	1040.71	1040.89	1041.02	1041.09	1041.18	1041.25
XS-30	4818.80	1038.65	1039.41	1039.82	1040.14	1040.37	1040.49	1040.62	1040.70	1040.87	1041.00	1041.08	1041.16	1041.23
XS-29	4798.50	1038.61	1039.37	1039.78	1040.10	1040.33	1040.45	1040.58	1040.65	1040.82	1040.95	1041.02	1041.11	1041.16

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Table 16 Computed flood frequency water levels (continued)

Cross Section	River Station (m)	Flood Return Period and Discharge (m^3/s)												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year
		59	113	152	190	221	240	262	277	313	343	361	383	397
		Water Surface Elevation (m)												
XS-28	4743.90	1038.55	1039.31	1039.72	1040.05	1040.28	1040.40	1040.53	1040.61	1040.79	1040.93	1041.00	1041.09	1041.15
XS-27	4599.80	1038.35	1039.07	1039.46	1039.77	1039.98	1040.11	1040.25	1040.35	1040.56	1040.72	1040.81	1040.91	1040.98
XS-26	4395.50	1038.12	1038.85	1039.26	1039.59	1039.82	1039.96	1040.09	1040.18	1040.37	1040.51	1040.59	1040.69	1040.75
XS-25	4232.40	1037.85	1038.52	1038.87	1039.18	1039.37	1039.48	1039.60	1039.68	1039.86	1040.01	1040.08	1040.18	1040.24
XS-24	4056.20	1037.67	1038.31	1038.67	1038.97	1039.16	1039.28	1039.40	1039.48	1039.65	1039.77	1039.84	1039.92	1039.97
XS-23	3823.20	1037.44	1038.00	1038.32	1038.57	1038.74	1038.84	1038.95	1039.02	1039.19	1039.32	1039.39	1039.49	1039.54
XS-22	3648.20	1037.26	1037.84	1038.17	1038.42	1038.59	1038.69	1038.80	1038.87	1039.03	1039.16	1039.23	1039.32	1039.37
XS-21	3435.30	1036.98	1037.56	1037.88	1038.15	1038.34	1038.45	1038.57	1038.64	1038.82	1038.96	1039.04	1039.14	1039.20
XS-20	3241.50	1036.75	1037.33	1037.63	1037.88	1038.04	1038.12	1038.21	1038.27	1038.40	1038.51	1038.57	1038.64	1038.68
XS-19	2997.30	1036.35	1036.91	1037.19	1037.41	1037.57	1037.66	1037.76	1037.82	1037.96	1038.08	1038.15	1038.24	1038.29
XS-18	2821.60	1036.09	1036.67	1036.96	1037.19	1037.35	1037.44	1037.55	1037.61	1037.76	1037.88	1037.95	1038.05	1038.10
XS-17	2739.70	1035.94	1036.49	1036.79	1037.06	1037.26	1037.37	1037.49	1037.56	1037.72	1037.84	1037.92	1038.02	1038.07
XS-16	2625.90	1035.81	1036.42	1036.75	1037.04	1037.23	1037.34	1037.46	1037.54	1037.70	1037.83	1037.90	1038.01	1038.06
XS-15	2464.80	1035.59	1036.17	1036.47	1036.74	1036.95	1037.06	1037.19	1037.27	1037.47	1037.63	1037.71	1037.84	1037.89
XS-14	2316.20	1035.44	1036.00	1036.32	1036.62	1036.84	1036.96	1037.10	1037.18	1037.38	1037.54	1037.62	1037.75	1037.80
XS-13	2162.60	1035.25	1035.75	1036.07	1036.36	1036.57	1036.68	1036.81	1036.88	1037.06	1037.21	1037.29	1037.43	1037.48
XS-12	2031.60	1034.96	1035.54	1035.88	1036.19	1036.41	1036.53	1036.66	1036.74	1036.93	1037.08	1037.17	1037.30	1037.36
XS-11	1833.80	1034.63	1035.29	1035.66	1035.98	1036.22	1036.36	1036.51	1036.60	1036.81	1036.99	1037.08	1037.15	1037.22
XS-10	1625.00	1034.44	1035.14	1035.52	1035.84	1036.09	1036.23	1036.38	1036.47	1036.67	1036.84	1036.93	1037.03	1037.10
XS-09	1448.00	1034.28	1034.98	1035.38	1035.72	1035.96	1036.11	1036.26	1036.35	1036.57	1036.73	1036.82	1036.93	1037.00
XS-08	1215.50	1033.93	1034.52	1034.84	1035.11	1035.30	1035.41	1035.54	1035.62	1035.80	1035.94	1036.03	1036.13	1036.19
XS-07	989.40	1033.61	1034.15	1034.46	1034.72	1034.91	1035.01	1035.13	1035.20	1035.36	1035.48	1035.55	1035.64	1035.69
XS-06	819.00	1033.21	1033.74	1034.05	1034.31	1034.49	1034.59	1034.71	1034.78	1034.93	1035.05	1035.13	1035.21	1035.26
XS-05	580.30	1032.79	1033.31	1033.61	1033.86	1034.05	1034.16	1034.28	1034.36	1034.55	1034.69	1034.78	1034.87	1034.93
XS-04	443.00	1032.49	1033.06	1033.39	1033.66	1033.85	1033.96	1034.09	1034.17	1034.35	1034.49	1034.56	1034.66	1034.71
XS-03	216.60	1032.13	1032.73	1033.05	1033.29	1033.46	1033.56	1033.67	1033.74	1033.93	1034.07	1034.15	1034.25	1034.31
XS-02	104.90	1031.97	1032.54	1032.86	1033.09	1033.27	1033.37	1033.49	1033.57	1033.78	1033.93	1034.01	1034.09	1034.16
XS-01	0.00	1031.88	1032.46	1032.79	1033.03	1033.22	1033.33	1033.45	1033.53	1033.73	1033.87	1033.95	1034.05	1034.11

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4.3.5 Model Sensitivity

Varying the flood frequency estimates, downstream boundary condition and Manning's roughness changes computed water levels, and consequently flood depths and inundation limits. The sensitivity of computed water levels to these variations were evaluated to gain an indication of model error range and to identify the relative sensitivity to each parameter. The 100-year flood was used as the baseline for this sensitivity analyses. A summary of the sensitivity analysis results is provided in the following sections. **Appendix D** provides detailed tabulated results.

4.3.5.1 Flood Frequency Estimates

The lower and upper limits of the 95% confidence interval for the 100-year instantaneous peak discharges (as shown in **Table 8**) were examined in the sensitivity analysis. **Table 17** provides a summary of the deviation from the 100-year flood levels for the lower 95% limit and the upper 95% limit discharge. Water surface elevations are presented in **Appendix D** and profiles are illustrated in **Figure 13.**

Table 17 Sensitivity analysis results for variation in 100-year flood frequency estimates

River	Difference from Baseline Profile (m)			
	Lower Flood Frequency Estimates		Higher Flood Frequency Estimates	
	Maximum	Average	Maximum	Average
Milk River	-0.15	-0.12	0.16	0.14

4.3.5.2 Downstream Boundary Condition

A starting water surface elevation at the downstream boundary is necessary for the HEC-RAS model to begin calculations. The adopted downstream boundary condition was based on a normal depth approximation, where the starting water level was calculated by Manning's equation with a specified energy slope equal to 0.0010 m/m. A plausible range of uncertainty in estimating the energy grade line slope is approximately ±20%, which resulted in a low value of 0.0008 m/m and a high value of 0.0012 m/m.

The results are listed in **Appendix D** and the resulting water surface elevation profiles shown in **Figure 14**. Departures of the computed water surface elevations from the baseline condition steadily decrease to below 0.1 m about 819 m upstream of the boundary condition (near cross section XS-06). Beyond about that cross section (XS-06) computed water surface elevations are effectively independent of the downstream boundary condition – the response of the computed water level here to boundary level variations is indiscernible.

4.3.5.3 Manning's Roughness

Channel Roughness

The calibrated channel roughness on the Milk River was 0.03. To test the sensitivity of computed water levels to channel roughness, these values were adjusted ±15%. **Appendix D** lists the results of these tests and **Figure 15** shows the resulting water levels. A 15% increase (decrease) in main channel

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roughness results in an average water level increase (decrease) of 0.16 m (-0.18 m) along the study reach. **Table 18** lists statistics on the differences.

Overbank Roughness

The adopted overbank roughness on the Milk River study reach was 0.04. Sensitivity of computed 100-year flood levels was tested with a ±20% variation in overbank roughness. Overbank roughness was varied by a larger percent than channel roughness to reflect the potentially greater uncertainty in overbank roughness. **Appendix D** tabulates the results and **Figure 16** displays the resulting water levels. The computed water levels are not very sensitive to variations in overbank roughness. A 20% increase (decrease) in overbank roughness corresponds to a water level increase (decrease) along the study reach of 0.02 m (-0.03 m) on average. **Table 18** lists statistics on the differences.

Table 18 Sensitivity analysis results for variation in Manning's roughness

Sensitivity Parameter	Difference from Baseline Profile (m)			
	Lower Roughness		Higher Roughness	
	Maximum	Average	Maximum	Average
Channel Roughness	-0.29	-0.18	0.25	0.16
Overbank Roughness	-0.05	-0.03	0.04	0.02

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5 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 flood frequency flow estimates corresponding to return periods ranging from 2 to 1000 years. **Appendix E** contains all the flood inundation maps. The following sections describe the flood inundation map production process.

5.1 Methodology

The flood inundation maps were created in five steps:

1. A water surface elevation (WSE) triangular irregular network (TIN) is created, representing a contiguous flood level profile along the modelled river reach.
2. A WSE grid with the same grid geometry as the underlying DTM is generated. Elevation values are assigned to each grid cell, based on the corresponding WSE TIN value.
3. A depth grid, having the same grid geometry as the WSE grid, is generated by subtracting DTM elevation values from the corresponding WSE grid value.
4. Inundation polygons are generated from the positive depths. Negative depths indicating dry cells are assigned a *NoData* value. Inundation polygons are further processed by smoothing and removing “isolated” wetted areas not directly inundated and “holes” (very small dry areas).
5. WSE and depth grids are clipped to the smoothed inundation extent polygons.

The WSE TINs, WSE and depth grids, and the inundation polygons were created using standard ArcGIS tool sets and were stored in a conventional Esri file format.

5.2 Water Surface Elevation TIN Modifications

For complex flood plain and river planform geometries the inundation extent does not necessarily follow the sloping surface of the main channel (particularly in off channel and backwater areas). For these cases, additional information is required to inform the TIN – resulting in a more realistic water surface profile in complex off channel areas that do not necessarily follow the slope of the main channel. For this study, the water surface elevation TINs were modified in off channel areas to provide a more realistic water surface. The differences between flood extents following the sloping surface of the main channel and the modified surface (in these off channel areas) was subtle.

5.3 Flood Inundation Areas

The impacts of flooding on developed areas and infrastructure are evident in the flood inundation maps (**Appendix E**). **Table 19** lists notable flood impacted areas and provides an overview of flood magnitude ranges for residential, commercial, industrial, and other notable facilities. The table lists areas from upstream to downstream, with left (right) floodplain areas on the left (right) side of the table. The middle of the table shows the cross section numbers nearest to each flooded area to assist in cross-referencing with the inundation mapping libraries. The grey shaded boxes provide a graphical display of

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the approximate range of flood frequency magnitudes impacting each area. For all flood inundation areas please refer to **Appendix E**.

Impacts to bridges are illustrated in the computed flood level frequency profiles where low chord and high chord elevations are indicated on the profile plots **(Figure 12**). Up to and including the calculated 1,000-year flood level, no flood exceeds the high chord elevation of any bridge. The low chord elevation of only the Railway Street bridge is exceeded by the 1000-year flood scenario.

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Table 19 Overview of the range of flood magnitudes for areas impacted by flooding

Impacted Areas along Left Floodplain													Cross Section Reference	Impacted Areas along Right Floodplain												
2-YR	5-YR	10-YR	20-YR	35-YR	50-YR	75-YR	100-YR	200-YR	350-YR	500-YR	750-YR	1000-YR		2-YR	5-YR	10-YR	20-YR	35-YR	50-YR	75-YR	100-YR	200-YR	350-YR	500-YR	750-YR	1000-YR
Buildings west of Range Road 164													XS-47													
									350	500	750	1K														
													XS-40	Buildings at Range Road 163												
																									750	1K
8 Flags Campground													XS-28													
		10	20	35	50	75	100	200	350	500	750	1K														
Buildings west of Range Road 163													XS-26													
								200	350	500	750	1K														

Note: shaded areas indicate the flood frequencies impacting the respective area.

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6 FLOODWAY DETERMINATION

6.1 Design Flood Selection

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. This is a flood with a statistical 100-year return period, also commonly referred to as the "one in one hundred year flood".

The 100-year flood was selected as the open water design flood for the Milk River study reach. The discharge values used for the open water design flood correspond to the 100-year return period discharge of 277 m^3/s, listed in **Table 8**.

6.2 Floodway and Flood Fringe Terminology

Flood hazard identification involves the delineation of floodway and flood fringe zones for a specified design flood under the FHIP Guidelines (Alberta Environment, 2011) and incorporates technical changes implemented in 2021 regarding how floodways are mapped in Alberta. The following describes relevant terminology from the FHIP Guidelines pertaining to this study.

Flood Hazard Mapping

Flood hazard mapping identifies the area flooded for the design flood and is typically divided into floodway and flood fringe zones. Flood hazard maps can also show additional flood hazard information, including areas of high hazard within the flood fringe and incremental areas at risk for more severe floods, like the 200-year and 500-year floods. Flood hazard mapping is typically used for long-term flood hazard area management and land-use planning.

Floodway

When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 100-year design flood. The floodway generally includes the main channel of a stream and a portion of the adjacent overbank area. Previously mapped floodways do not typically become larger when a flood hazard map is updated, even if the flood hazard area gets larger or design flood levels get higher.

Flood Fringe

The flood fringe is the portion of the flood hazard area outside of the floodway. The flood fringe typically represents areas with shallower, slower, and less destructive flooding during the 100-year design flood. However, areas with deep or fast moving water may also be identified as high hazard flood fringe within the flood fringe. Areas at risk behind flood berms may also be mapped as protected flood fringe areas.

Design Flood Levels

Design flood levels are the computed water levels associated with the design flood.

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6.3 Flood Hazard Identification

6.3.1 Design Flood Profile

The design flood profile levels were those calculated for the 100-year open water flood condition. The resulting design flood level values are listed in **Table 20**.

Table 20 Computed design flood levels

Cross Section	River Station (m)	Design Flood Level (m)
XS-56	8108.50	1043.65
XS-55	7888.90	1043.39
XS-54	7720.10	1043.28
XS-53	7476.10	1043.06
XS-52	7286.60	1042.99
XS-51	7077.30	1042.64
XS-50	6922.70	1042.38
XS-49	6716.20	1042.30
XS-48	6485.00	1042.02
XS-47	6310.80	1042.01
XS-46	6124.80	1041.93
XS-45	6007.10	1041.84
XS-44	5836.30	1041.64
XS-43	5744.30	1041.65
XS-42	5623.20	1041.56
XS-41	5465.10	1041.49
XS-40	5263.60	1041.24
XS-39	5154.70	1041.16
XS-38	5045.10	1041.13
XS-37	4995.40	1041.08
XS-36	4983.40	1041.01
XS-35	4948.90	1040.99
XS-34	4928.90	1040.97
XS-33	4909.50	1040.96
XS-32	4889.30	1040.89
XS-31	4848.70	1040.71
XS-30	4818.80	1040.70
XS-29	4798.50	1040.65
XS-28	4743.90	1040.61
XS-27	4599.80	1040.35
XS-26	4395.50	1040.18
XS-25	4232.40	1039.68
XS-24	4056.20	1039.48
XS-23	3823.20	1039.02
XS-22	3648.20	1038.87
XS-21	3435.30	1038.64
XS-20	3241.50	1038.27
XS-19	2997.30	1037.82
XS-18	2821.60	1037.61
XS-17	2739.70	1037.56
XS-16	2625.90	1037.54
XS-15	2464.80	1037.27
XS-14	2316.20	1037.18
XS-13	2162.60	1036.88
XS-12	2031.60	1036.74
XS-11	1833.80	1036.60
XS-10	1625.00	1036.47
XS-09	1448.00	1036.35
XS-08	1215.50	1035.62
XS-07	989.40	1035.20
XS-06	819.00	1034.78
XS-05	580.30	1034.36
XS-04	443.00	1034.17
XS-03	216.60	1033.74
XS-02	104.90	1033.57
XS-01	0.00	1033.53

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Figure 17 depicts the open water design flood level profiles for the Milk River study reach.

Classification: Public

6.3.2 Floodway Determination Criteria

The floodway typically represents the area of highest hazard where flows are deepest, fastest, and most destructive during the design flood. The following criteria are based on the FHIP guidelines and were used to delineate the floodway.

- Areas in which the depth of water exceeds 1 m or the flow velocities are greater than 1 m/s.
- In no case should the floodway boundary extend into the main river channel area.
- Exceptions may be made for small backwater areas, ineffective flow areas, and to support creation of a hydraulically smooth floodway.
- For reaches of supercritical flow, the floodway boundary should correspond to the edge of inundation or the main channel, whichever is larger – there were no conditions of supercritical flow for this study and so this criterion did not apply.
- Where a previous floodway exists and a flood hazard map is updated, the existing floodway will not change in most circumstances – a previous floodway did not exist and so this criterion did not apply.

The limits of the floodway are drawn in accordance with the aforementioned criteria. In some instances, the floodway limits are coincident with the inundation limits. This condition typically occurs when floodway limits are very close to the extent of inundation and there is no practical width of flood fringe. This is most evident along steep valley walls or high banks. Where these conditions were encountered, the floodway station was adjusted to the station of the water edge. These instances are evident in the floodway criteria map. The location where the floodway limit lines intersect the model cross section lines are denoted as the floodway limit stations. The floodway limit stations and the determination criteria for each cross section are tabulated in **Table 21.** Instances where the floodway limits were adjusted to the extent of inundation are annotated with an asterisk. In some cases where the main river channel criterion applied, the edge of the channel was also very near the 1 m depth contour – this provided a consistent reference line for delineating the floodway between these sections. The locations where the floodway limit line followed the 1 m depth contour as the edge of the main river channel are denoted in the table with a double asterisk. The final floodway limits were determined in consultation with the AEP project team.

DRAFT

Table 21 Floodway limits and determination criteria

Cross Section	River Station (m)	Left		Right	
		Floodway Limit Station (m)	Floodway Determination Criteria	Floodway Limit Station (m)	Floodway Determination Criteria
XS-54	7720.10	414.03	1 m depth	478.02	Main river channel*
XS-53	7476.10	357.13	1 m depth	778.82	1 m depth*
XS-52	7286.60	201.15	1 m depth	814.96	1 m depth*

Classification: Public

Table 21 Floodway limits and determination criteria (continued)

Cross Section	River Station (m)	Left		Right	
		Floodway Limit Station (m)	Floodway Determination Criteria	Floodway Limit Station (m)	Floodway Determination Criteria
XS-51	7077.30	27.55	Main river channel*	703.44	1 m depth*
XS-50	6922.70	36.85	Main river channel*	657.22	1 m depth*
XS-49	6716.20	32.51	Main river channel*	544.27	1 m depth*
XS-48	6485.00	56.31	Main river channel*	398.67	1 m depth*
XS-47	6310.80	313.50	Main river channel*	477.63	1 m depth*
XS-46	6124.80	59.38	1 m depth*	393.52	1 m depth
XS-45	6007.10	85.16	1 m depth*	540.70	1 m depth*
XS-44	5836.30	128.74	Main river channel*	523.47	1 m depth*
XS-43	5744.30	149.06	1 m depth*	445.89	1 m depth*
XS-42	5623.20	141.21	1 m depth*	259.67	1 m depth*
XS-41	5465.10	239.88	1 m depth*	1175.61	1 m depth*
XS-40	5263.60	302.69	1 m depth*	579.08	1 m depth*
XS-39	5154.70	298.85	1 m depth	352.54	Main river channel**
XS-38	5045.10	341.01	1 m depth	429.04	Main river channel**
XS-37	4995.40	376.59	Main river channel*	441.69	Main river channel*
XS-36	4983.40	377.62	Main river channel*	442.02	Main river channel*
XS-35	4948.90	377.81	Main river channel*	443.74	Main river channel*
XS-34	4928.90	378.85	Main river channel*	445.48	Main river channel*
XS-33	4909.50	377.74	Main river channel*	444.91	Main river channel*
XS-32	4889.30	379.92	Main river channel*	444.78	Main river channel*
XS-31	4848.70	399.72	Main river channel*	452.44	Main river channel*
XS-30	4818.80	392.33	Main river channel*	445.33	Main river channel*
XS-29	4798.50	392.04	Main river channel*	444.16	Main river channel*
XS-28	4743.90	406.99	1 m depth	452.04	Main river channel*
XS-27	4599.80	223.64	Main river channel*	257.31	1 m depth
XS-26	4395.50	115.51	Main river channel*	168.99	Main river channel*
XS-25	4232.40	24.20	Main river channel*	57.87	1 m depth
XS-24	4056.20	57.80	Main river channel**	99.65	Main river channel*
XS-23	3823.20	50.82	Main river channel*	86.91	1 m depth
XS-22	3648.20	25.34	Main river channel*	81.05	Main river channel*

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Classification: Public

Table 21 Floodway limits and determination criteria (continued)

Cross Section	River Station (m)	Left		Right	
		Floodway Station (m)	Floodway Determination Criteria	Floodway Station (m)	Floodway Determination Criteria
XS-21	3435.30	89.61	1 m depth	140.68	Main river channel*
XS-20	3241.50	109.81	Main river channel**	153.41	Main river channel*
XS-19	2997.30	90.48	Main river channel**	135.17	Main river channel*
XS-18	2821.60	22.08	Main river channel*	82.58	1 m depth
XS-17	2739.70	13.16	Main river channel*	130.31	1 m depth
XS-16	2625.90	117.02	Main river channel**	201.05	1 m depth
XS-15	2464.80	195.91	1 m depth	244.96	Main river channel*
XS-14	2316.20	93.74	Main river channel**	172.48	Main river channel*
XS-13	2162.60	27.41	Main river channel*	74.15	Main river channel**
XS-12	2031.60	122.58	Main river channel*	174.34	Main river channel**
XS-11	1833.80	74.50	Main river channel*	150.57	1 m depth
XS-10	1625.00	202.15	1 m depth	256.92	1 m depth
XS-09	1448.00	143.89	1 m depth	208.87	Main river channel*
XS-08	1215.50	97.50	Main river channel*	128.66	Main river channel**
XS-07	989.40	63.43	Main river channel*	106.82	Main river channel*
XS-06	819.00	26.94	Main river channel*	73.40	Main river channel*
XS-05	580.30	124.94	1 m depth	170.82	Main river channel*
XS-04	443.00	68.38	1 m depth	124.80	Main river channel*
XS-03	216.60	51.51	Main river channel*	93.77	Main river channel**

* denotes those instances where the floodway limit was adjusted to the extent of inundation.
** denotes locations where the 1 m depth contour well-approximated the edge of main river channel.

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6.3.3 Floodway Criteria Maps

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

Polygons representing areas of depth 1 m or greater and 1 m depth contour lines were derived from the flood depth grid. The depth contours were then filtered and smoothed using the same parameters and procedures as those applied to determine the inundation extents (also described in **Section 5**).

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

The floodway criteria maps provide visual documentation of the results of the floodway determination and depict the limits of the floodway and flood fringes for the design flood. The floodway criteria maps are provided in **Appendix F**. The information documented on the maps include:

- Inundation extents for the design flood.
- Areas where the depth of water is 1 m or greater and the corresponding 1 m depth contour.
- The portions of each cross section where the computed velocity is 1 m/s or faster.
- The floodway limit line.
- The floodway station locations.
- Stranded areas of dry ground within the flood hazard area.
- The location and extent of all cross sections used in the HEC-RAS model.

6.3.4 Flood Hazard Maps

The flood hazard maps depict the resulting floodway and flood fringe zones for the design flood. The limits of the floodway were delineated by the floodway boundary depicted in the floodway criteria map. Areas of high ground or areas of depth less than 1 m inside the floodway boundaries were included as part of the floodway and the resulting floodway represents a single contiguous polygon.

The extent of the design flood depicted in the floodway criteria map delineates the limits of the flood fringe extending beyond the floodway. Unlike the areas of high ground found within the floodway, high ground or “dry areas” within the flood fringe are not symbolized as being inundated. High hazard flood fringe areas are differentiated with a dotted symbology.

The resulting flood hazard maps are provided as **Appendix G**.

6.3.4.1 Areas in the Floodway

There were no notable areas of interest within the overbank areas in the floodway.

6.3.4.2 Areas in the High Hazard Flood Fringe

There were no notable areas of interest within the overbank areas in the high hazard flood fringe.

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Classification: Public

6.3.4.3 Areas in the Flood Fringe

The flood fringe includes all inundated areas outside the limits of the floodway and high hazard flood fringe. The 8 Flags Campground was the only notable area within the flood fringe include.

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Classification: Public

7 POTENTIAL CLIMATE CHANGE IMPACTS

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

7.1 Comparative Scenarios

The assessment was based on a comparison between the computed 100-year flood levels and those computed with discharges that were 10, 20, and 30 percent greater than the 100-year flood discharge. This approach is consistent with guidelines prepared by the Engineers and Geoscientists British Columbia (EGBC). EGBC (2018) recommends that for basins where no historical trend is detectable in local or regional streamflow magnitude frequency relations, a 10 percent upward adjustment in design discharge be applied to account for potential future changes in water input from precipitation. On the other hand, if a statistically significant trend is detected, a 20 percent adjustment may be appropriate. A third, 30 percent adjustment scenario was added for comparison.

7.2 Results

The magnitude of the increases was found to be fairly uniform along the study reach. The average increase in water levels for a 10, 20, and 30 percent increase from the 100-year flood discharge were 0.15 m, 0.27 m and 0.40 m, respectively. **Figure 18** plots a comparison between the computed 100-year flood level profile and profiles computed with discharges that are 10, 20, and 30 percent greater than the 100-year flood discharge.

7.3 Supplementary Information

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

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8 CONCLUSIONS

The Milk River Flood Study was done according to FHIP Guidelines, incorporating technical changes implemented in 2021 regarding how floodways are mapped in Alberta. The objectives of this study were to assess and identify flood hazards along a 7.2 km long reach of the Milk River within Warner County, including the town of Milk River.

The Milk River Flood Study was divided into five major project components: Survey and Base Data Collection, Open Water Hydrology Assessment, Open Water Hydraulic Modelling, Open Water Flood Inundation Mapping, and Design Flood Hazard Mapping. This report summarizes the work of all five components.

The collection of survey and base data primarily supports the hydraulic modelling and flood mapping. Cross sections were surveyed along the study reach. In total, 54 cross sections were surveyed using a combination of boat-based bathymetric and ground surveys to complement the LiDAR-derived DTM. In addition, geometric details were collected for four bridges.

The primary purpose of the open water hydrology assessment is to develop flood frequency estimates for Milk River at Milk River (WSC Station 11AA005), in support of the hydraulic modelling and flood mapping tasks. The current flood frequency estimates are comparable with previous flood frequency estimates (AENV, 2001 and 2013).

A numerical model was developed using the HEC-RAS computer program distributed and maintained by the U.S. Army Corps of Engineers Hydraulic Engineering Center. River bathymetry and digital terrain data from the Survey and Base Data Collection component as well as flood frequency estimates from the Open Water Hydrology Assessment component were used to develop, calibrate, and apply the open water hydraulic model. The model was calibrated to the June 2002 (peak discharge 251 m^3/s) and June 2014 (peak discharge 145 m^3/s) flood events. Water levels computed by the calibrated model were on average 0.03 m below observed 2002 flood event highwater marks and 0.02 m below observed 2014 flood event highwater marks. The calibrated model was used to calculate water surface profiles for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year flood frequency return period discharges. All bridges along the study reach are above the computed 100-year flood level. The low chord of the Railway Street bridge is the only bridge, impacted by the 1000-year flood magnitude.

Flood inundation maps were created for all the 13 flood frequency magnitudes and organized together into a single flood inundation map library. The 8 Flags Campground would be affected by direct inundation at the 10-year flood level. A few other buildings within the study area would be affected in 200-year and larger floods.

The floodway criteria maps document the open water flood hazard identification criteria and resulting floodway boundaries. These maps depict the rationale supporting the design flood hazard mapping showing the extent of the flood hazard areas (floodway, flood fringe, and high hazard flood fringe). No notable overbank areas are observed within the floodway.

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Classification: Public

9 REFERENCES

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Classification: Public

FIGURES

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FLOOD FREQUENCY ESTIMATE LOCATION

WSC STATION 11AA005

STUDY REACH

TOWN OF MILK RIVER

ATS QUARTER SECTION BOUNDARY

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:15,000

0 100 200 400 600 M

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Job: 1006666 | *Date: 15-FEB-2022*

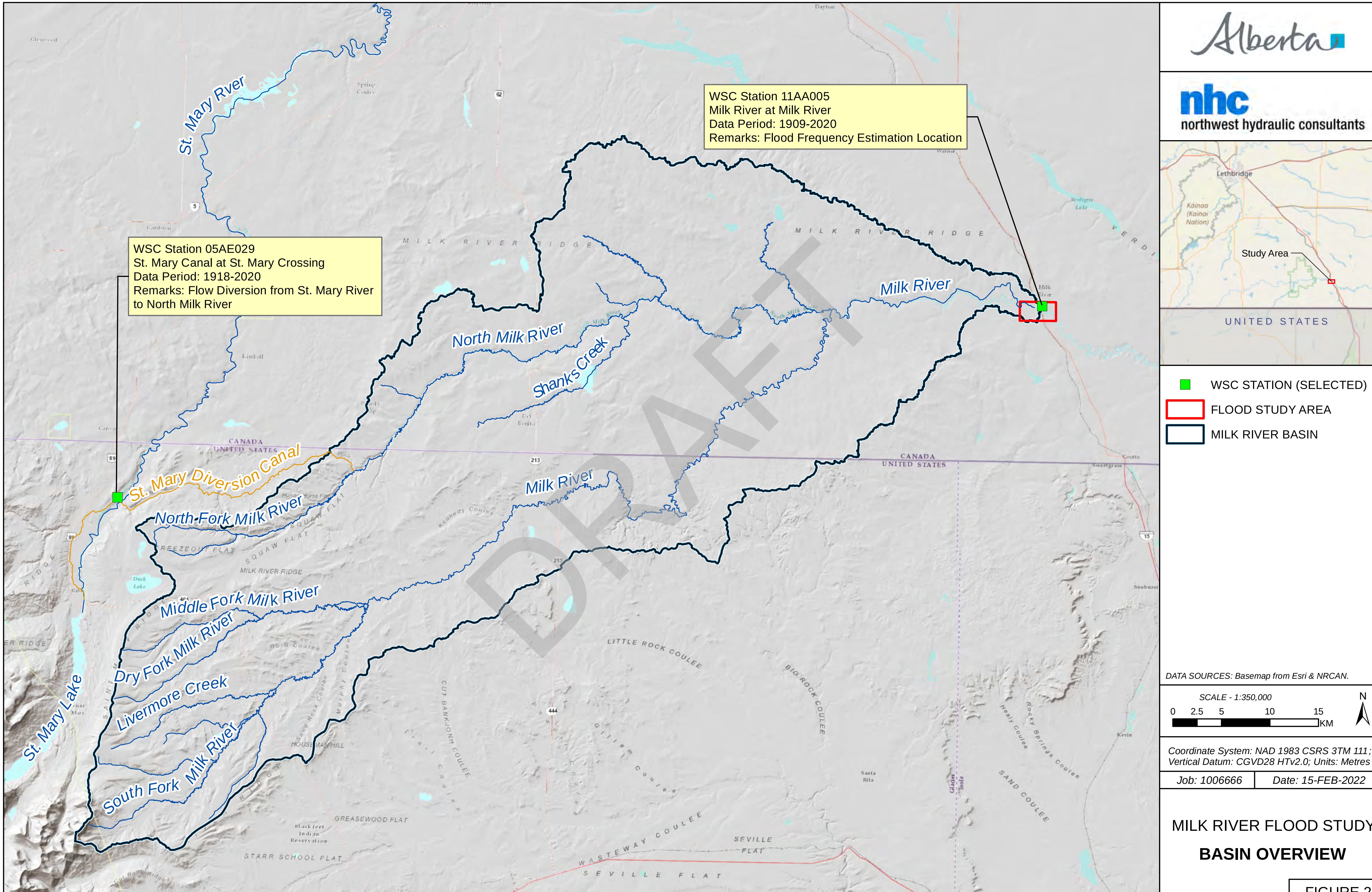
MILK RIVER FLOOD STUDY

STUDY AREA

FIGURE 1

REH, P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_Figure 1_StudyArea.mxd

Classification: Public



Classification: Public

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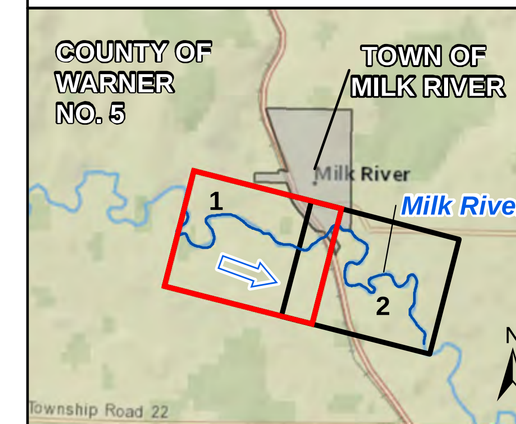


- FLOW DIRECTION
- CONTROL POINT
- SURVEY POINT
- WSC STATION (11AA005)
- STUDY REACH
- MODEL CROSS SECTION
- BRIDGE
- LOCAL ROAD
- PROVINCIAL HIGHWAY
- RAILWAY
- STUDY LIMIT
- TOWN OF MILK RIVER

SCALE - 1:7,500

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	DJH

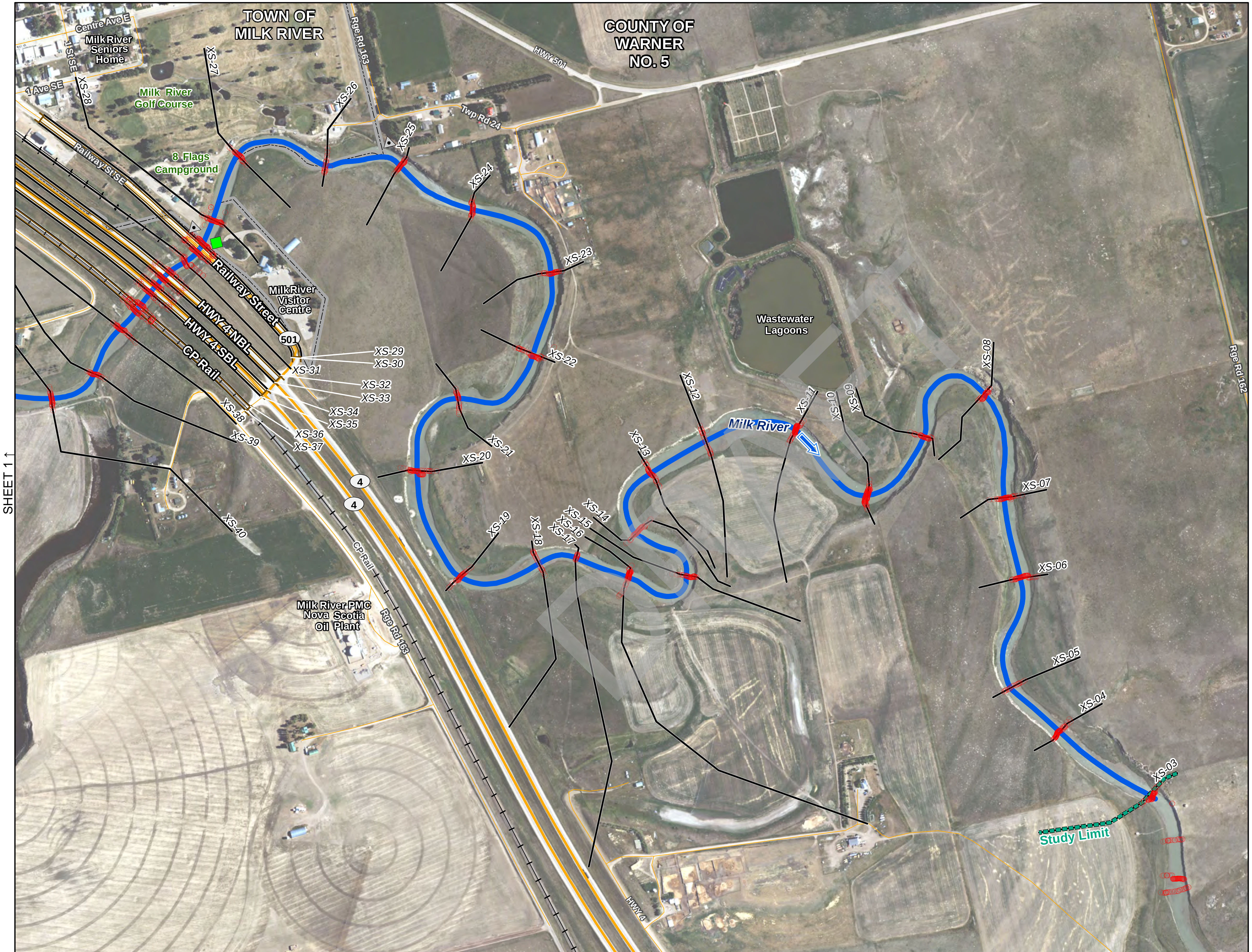
Job: 1006666	Date: 24-MAR-2022

MILK RIVER FLOOD STUDY

SURVEY OVERVIEW

JY P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_Figure 3_SurveyandStructure.mxd

Classification: Public



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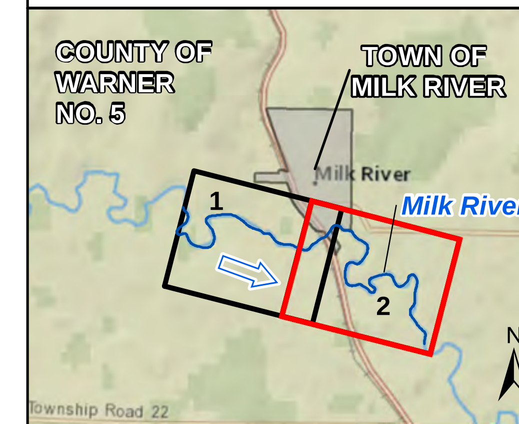

FLOW DIRECTION
CONTROL POINT
SURVEY POINT
WSC STATION (11AA005)
STUDY REACH
MODEL CROSS SECTION
BRIDGE
LOCAL ROAD
PROVINCIAL HIGHWAY
RAILWAY
STUDY LIMIT
TOWN OF MILK RIVER

SCALE - 1:7,500
0 100 200 M
N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer MMM	GIS JY	Reviewer DJH

Job: 1006666	Date: 24-MAR-2022

MILK RIVER FLOOD STUDY
SURVEY OVERVIEW

SHEET 2 OF 2	FIGURE 3

JY P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_Figure 3_SurveyandStructure.mxd

1948 Flood: Looking north between CP Rail and old Highway 4 bridge (June 18, 1948)

1948 Flood: Looking downstream at old Highway 4 bridge (June 18, 1948)

1964 Flood: Looking downstream at highway 4 Bridge (June 9, 1964)

1964 Flood: Pipeline under water at Milk River

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Notes: 1. Flood photographs are obtained from Alberta Transportation flood documentation at Highway 4 bridge (AT Bridge File No.1426).

MILK RIVER FLOOD STUDY

OPEN WATER FLOOD PHOTOGRAPHS FOR MILK RIVER AT MILK RIVER

Job: 01006666 *Date: 14-MAR-2022*

FIGURE 4

Classification: Public

1911 Flood: Ice jam on the first bridge constructed over the Milk River

1947 Flood: Ice Jam at Milk River

1960 Flood: Looking upstream towards the Town of Milk River

1965 Flood: Looking north over Writing-on-Stone campground showing irrigation pump house surrounded and water upto camp shelter

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Notes: 1. Flood photographs are obtained from Alberta Transportation flood documentation at Highway 4 bridge (AT Bridge File No.1426).

MILK RIVER FLOOD STUDY

ICE JAM FLOOD PHOTOGRAPHS FOR MILK RIVER AT MILK RIVER

Job: 01006666 | Date: 14-MAR-2022 | FIGURE 5

Classification: Public

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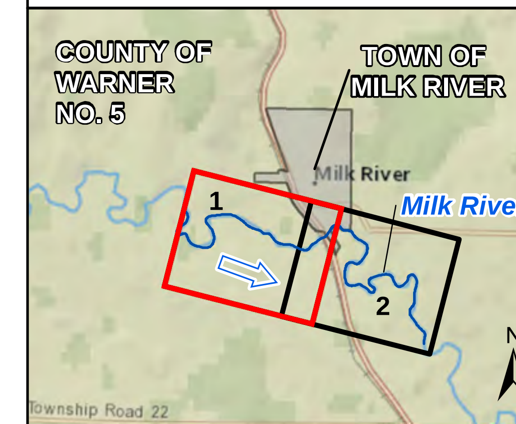

- FLOW DIRECTION
- 2014 HIGHWATER MARK
- 2002 HIGHWATER MARK
- SUSPECT HIGHWATER MARK
- STUDY LIMIT
- BRIDGE
- MODEL CROSS SECTION
- STUDY REACH
- TOWN OF MILK RIVER

SCALE - 1:7,500

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer MMM	GIS JY	Reviewer DJH
Job: 1006666	Date: 24-MAR-2022	

MILK RIVER FLOOD STUDY

HIGHWATER MARK LOCATIONS

SHEET 1 OF 2 | FIGURE 6

J:\P_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_Figure 6_HWMs.mxd

Classification: Public

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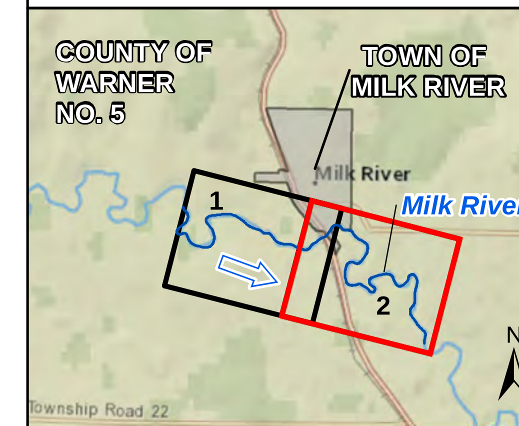


- FLOW DIRECTION
- 2014 HIGHWATER MARK
- 2002 HIGHWATER MARK
- SUSPECT HIGHWATER MARK
- STUDY LIMIT
- BRIDGE
- MODEL CROSS SECTION
- STUDY REACH
- TOWN OF MILK RIVER

SCALE - 1:7,500

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	DJH

Job: 1006666	Date: 24-MAR-2022

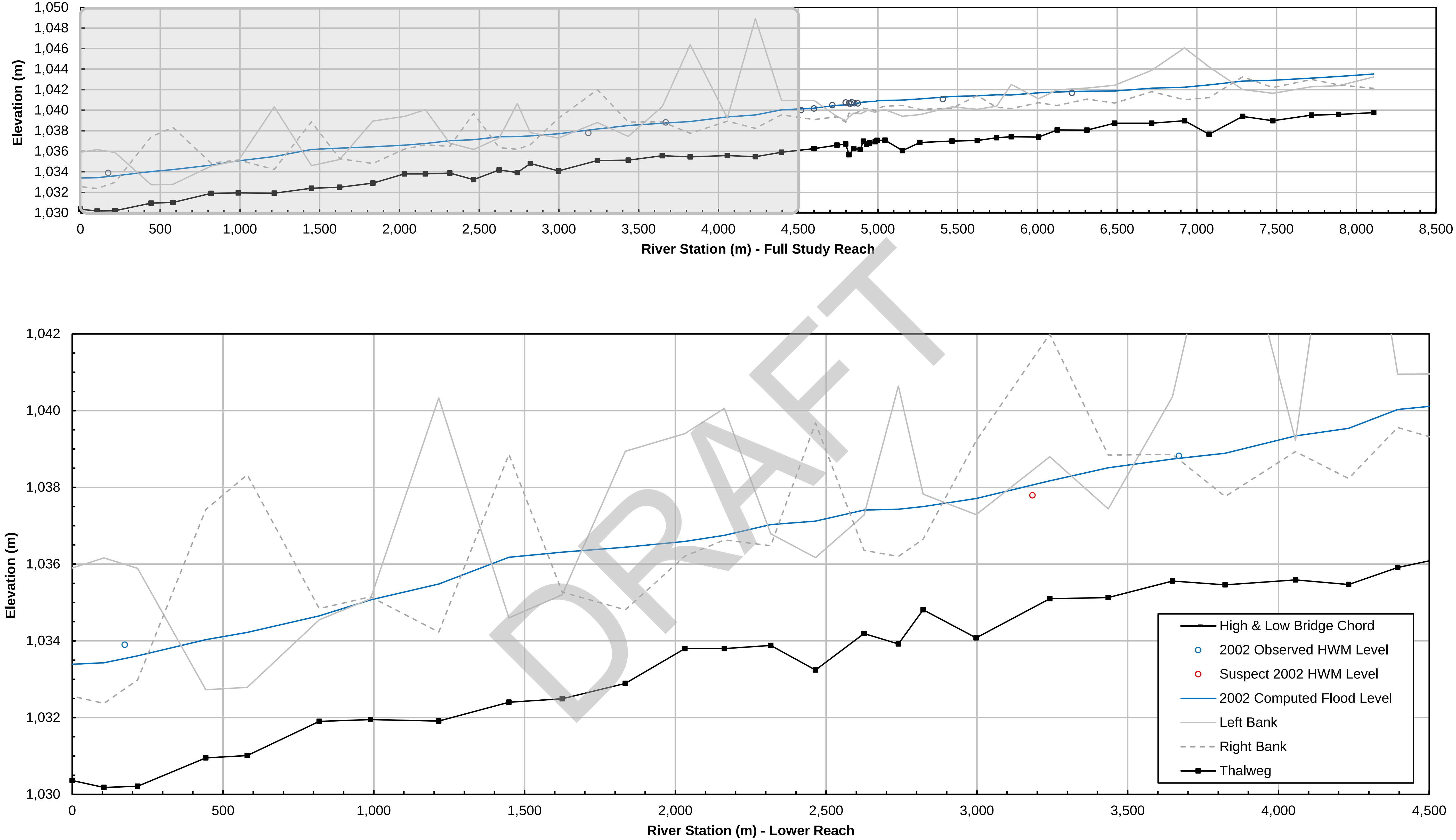
MILK RIVER FLOOD STUDY

HIGHWATER MARK LOCATIONS

SHEET 2 OF 2	FIGURE 6

JY_P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_Figure 6_HWMs.mxd

Classification: Public



Job: 01006666

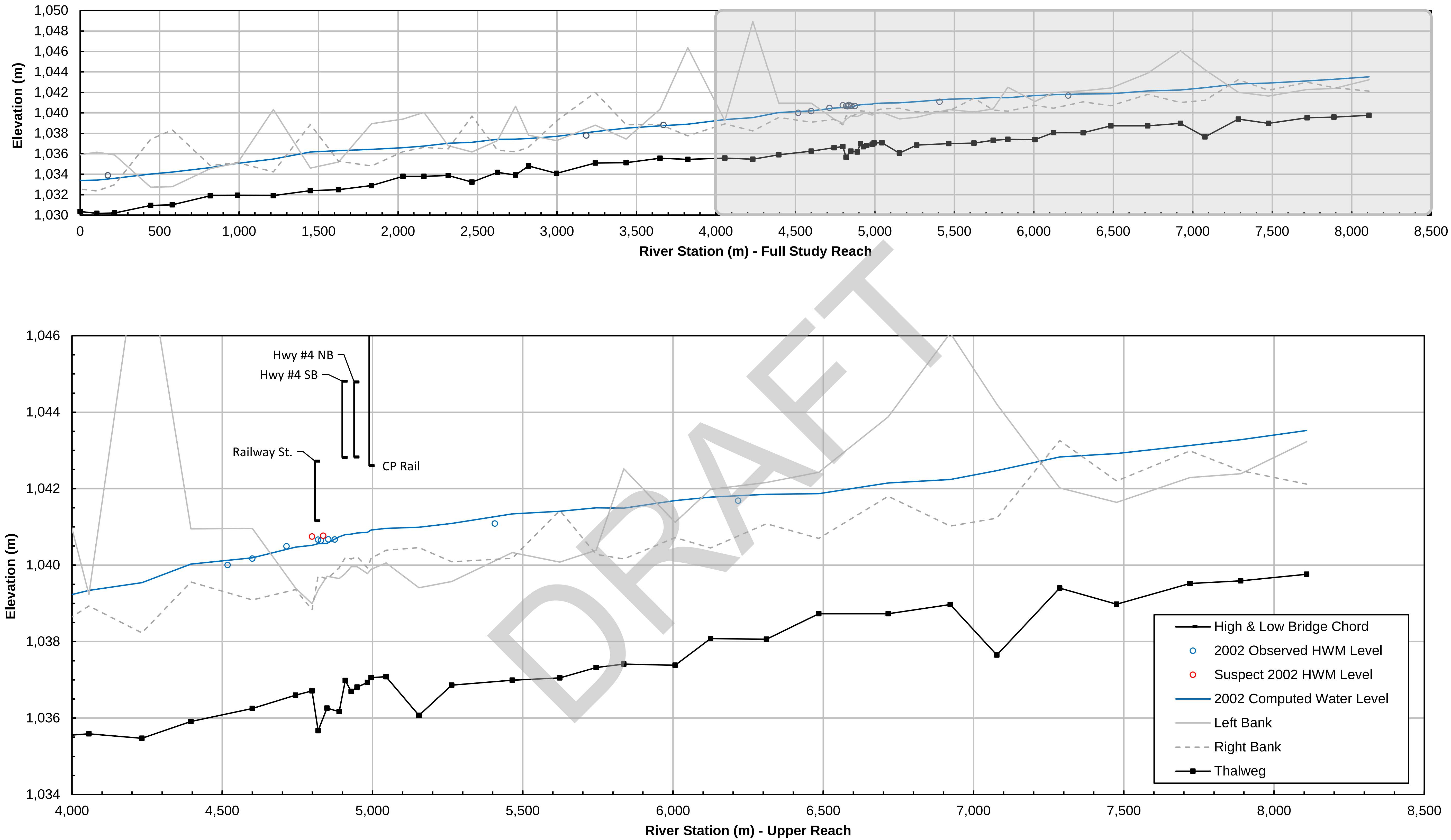
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS – 2002 FLOOD

FIGURE 7A

Classification: Public



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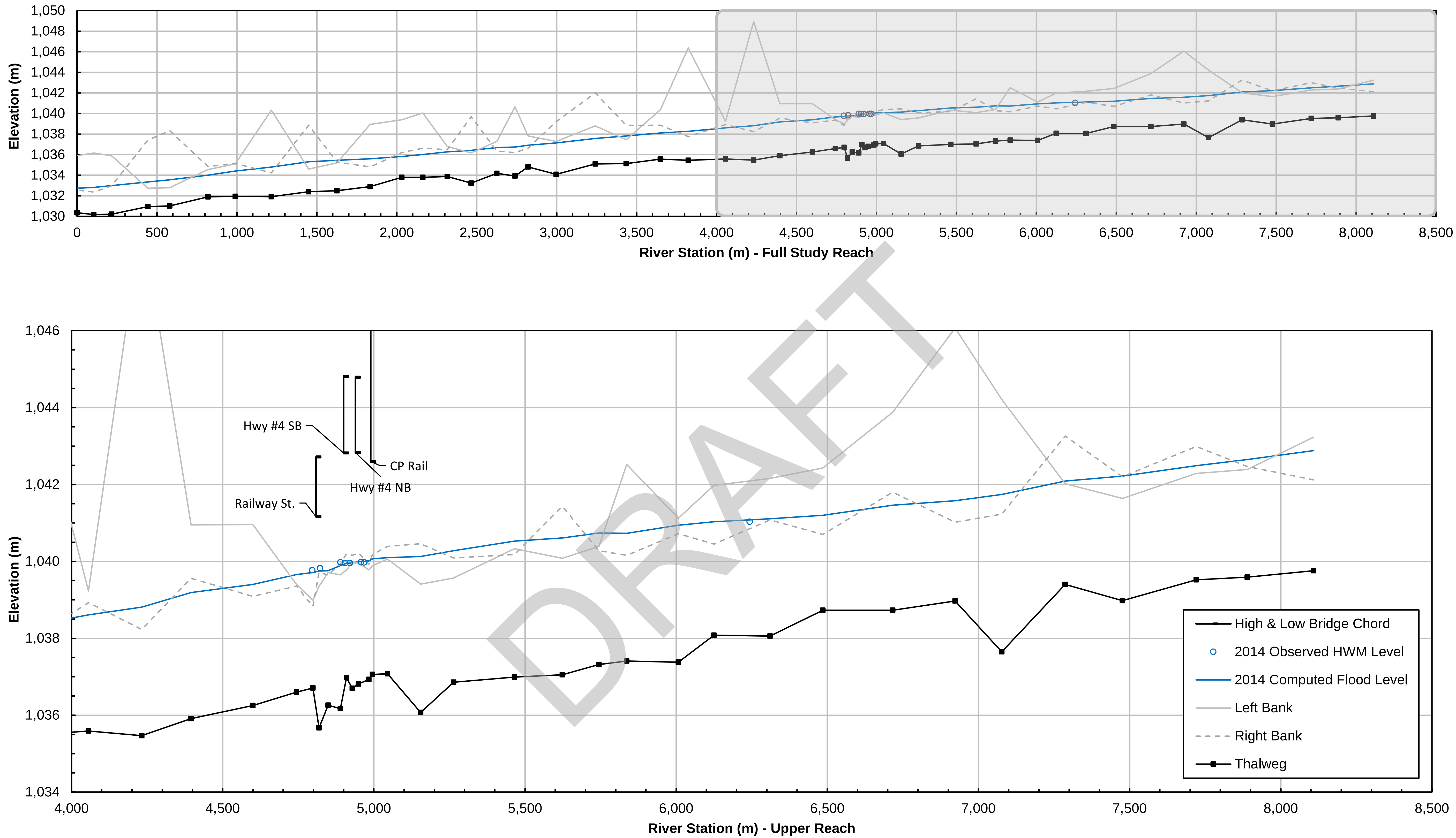
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS – 2002 FLOOD

FIGURE 7B

Classification: Public



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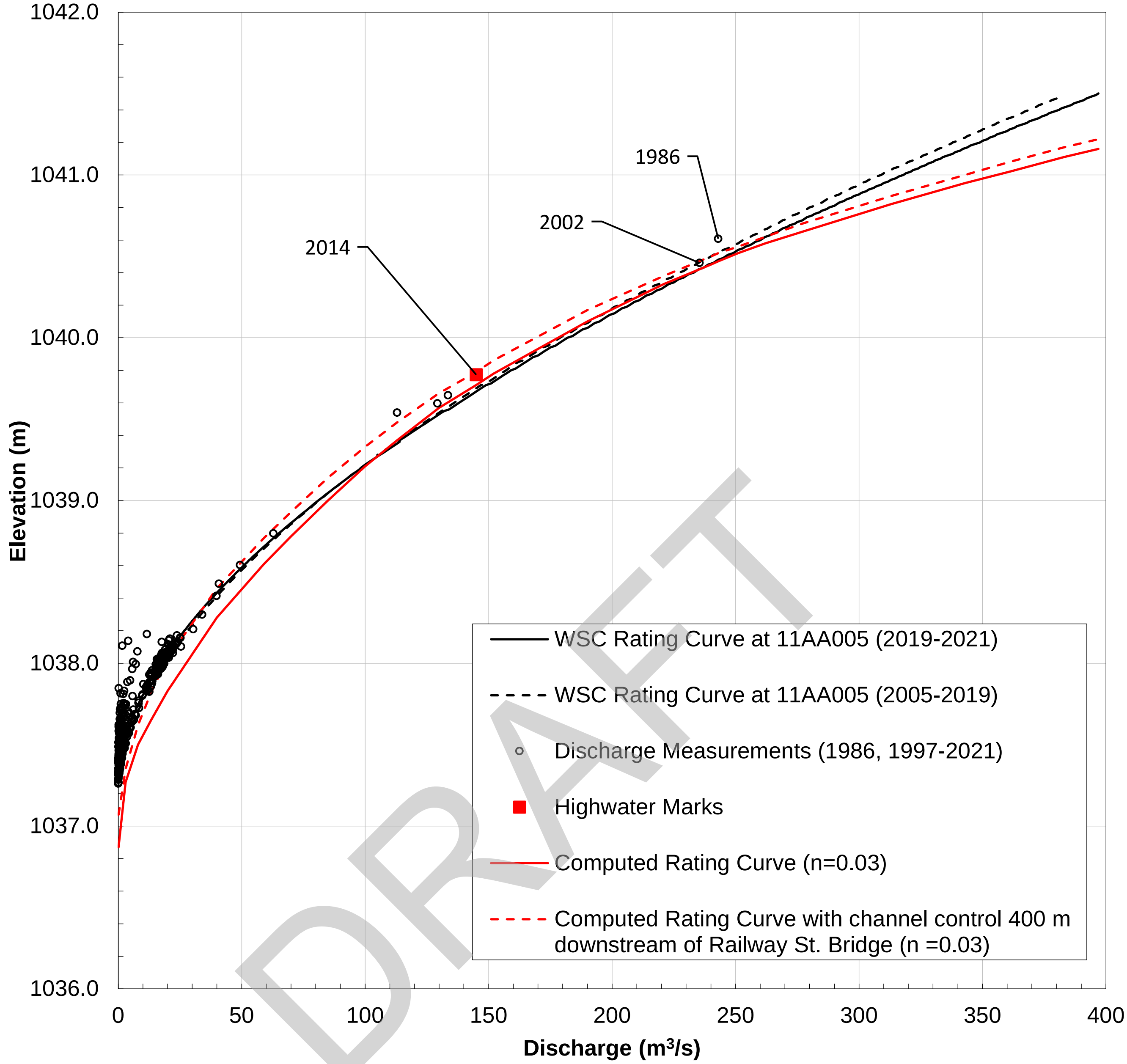
MILK RIVER FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS – 2014 FLOOD

FIGURE 8

Classification: Public



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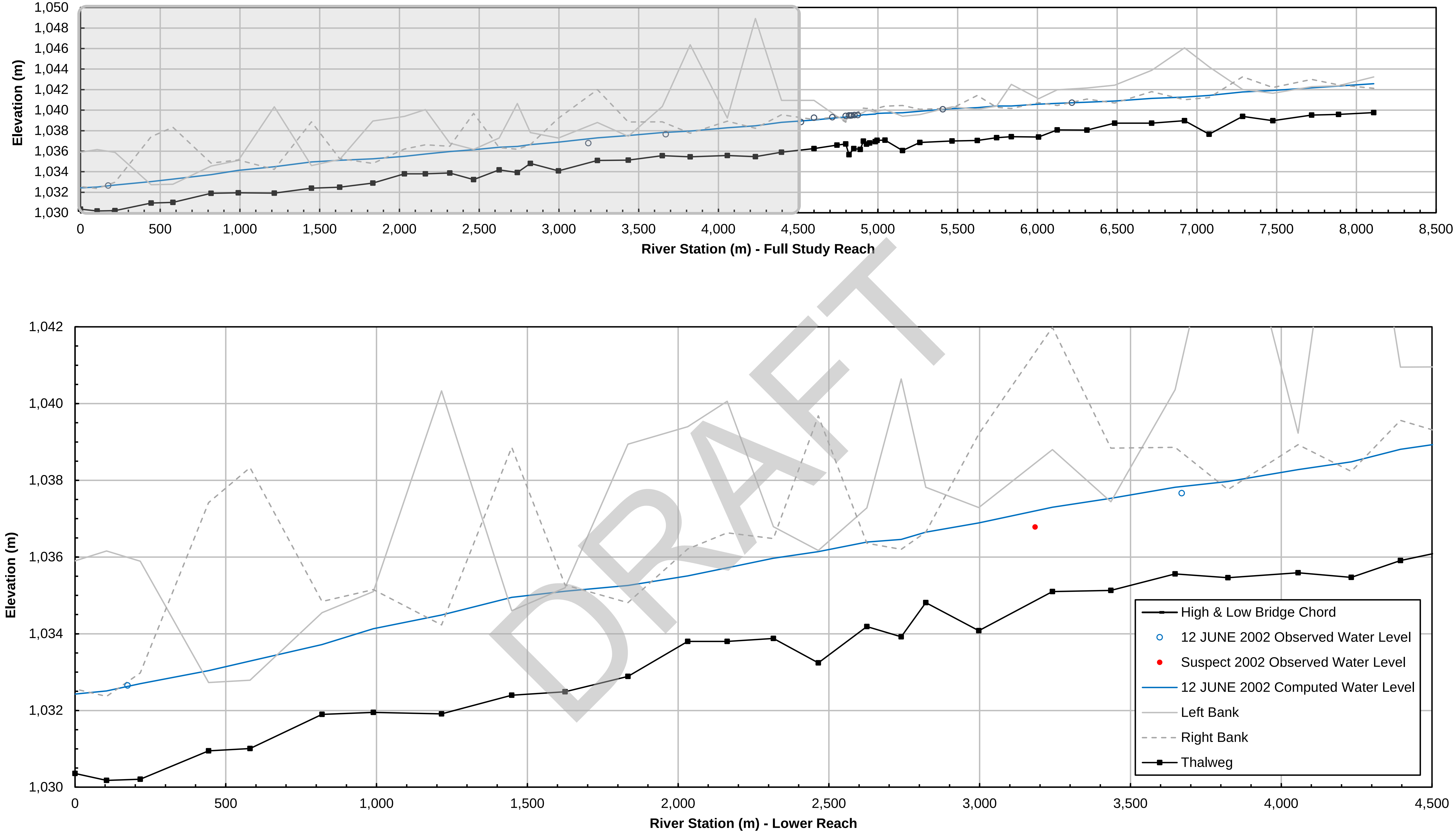
MILK RIVER FLOOD STUDY

COMPARISON BETWEEN COMPUTED AND REPORTED WSC RATING CURVE DATA FOR MILK RIVER AT MILK RIVER (WSC STATION 11AA005)

Job: 1006666	*Date: 14-MAR-2022*	FIGURE 9

Classification: Public



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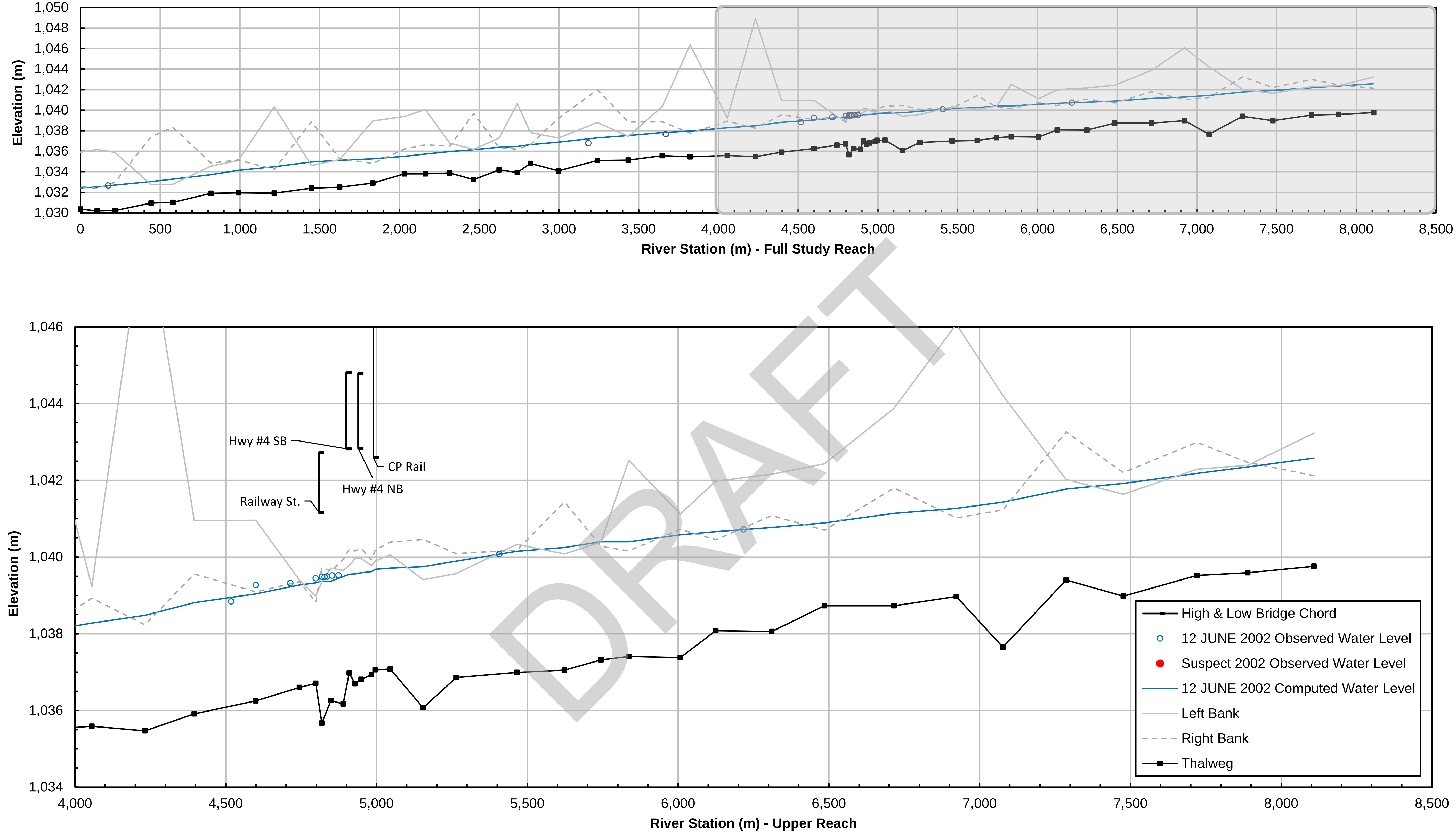
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS – 12 JUNE 2002

FIGURE 10A

Classification: Public



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MILK RIVER FLOOD STUDY

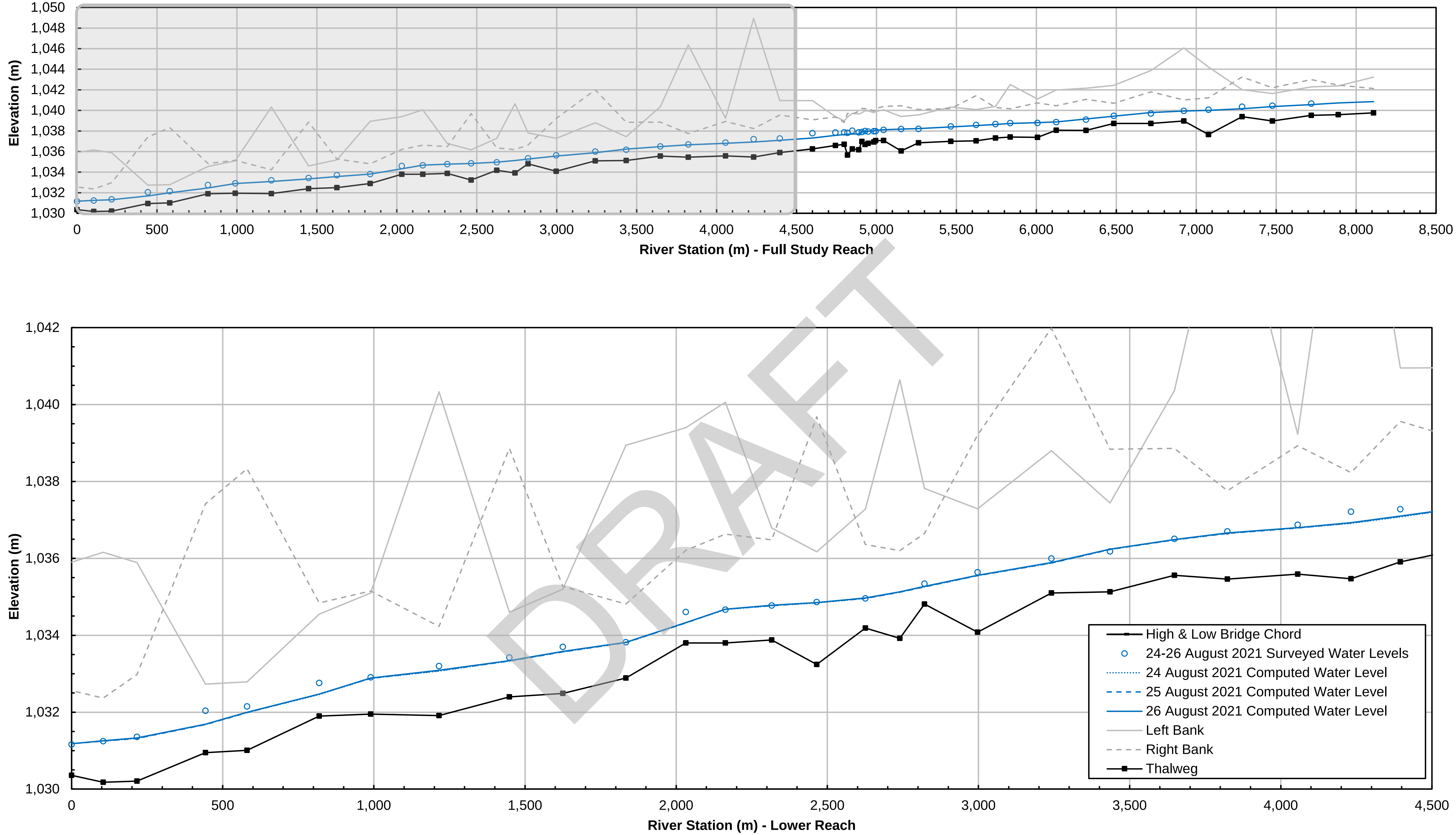
COMPUTED VS OBSERVED WATER LEVELS – 12 JUNE 2002

Job: 01006666

Date: 14-MAR-2022

FIGURE 10B

Classification: Public



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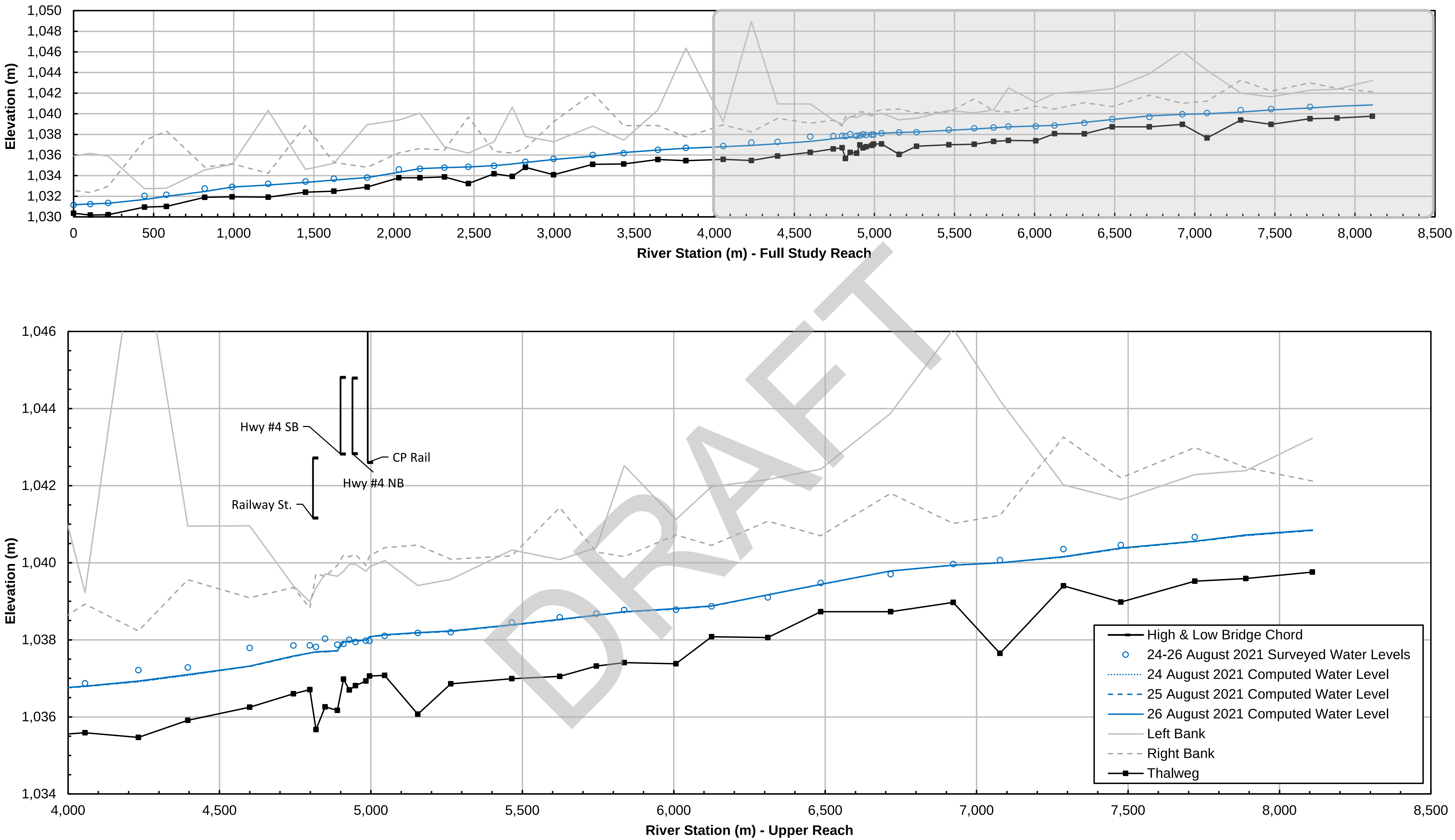
MILK RIVER FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS – 2021 BATHYMETRY SURVEY

Job: 01006666 | *Date: 14-MAR-2022*

FIGURE 11A

Classification: Public



MILK RIVER FLOOD STUDY

COMPUTED VS OBSERVED WATER LEVELS – 2021 BATHYMETRY SURVEY

FIGURE 11B

Job: 01006666 | *Date: 14-MAR-2022*

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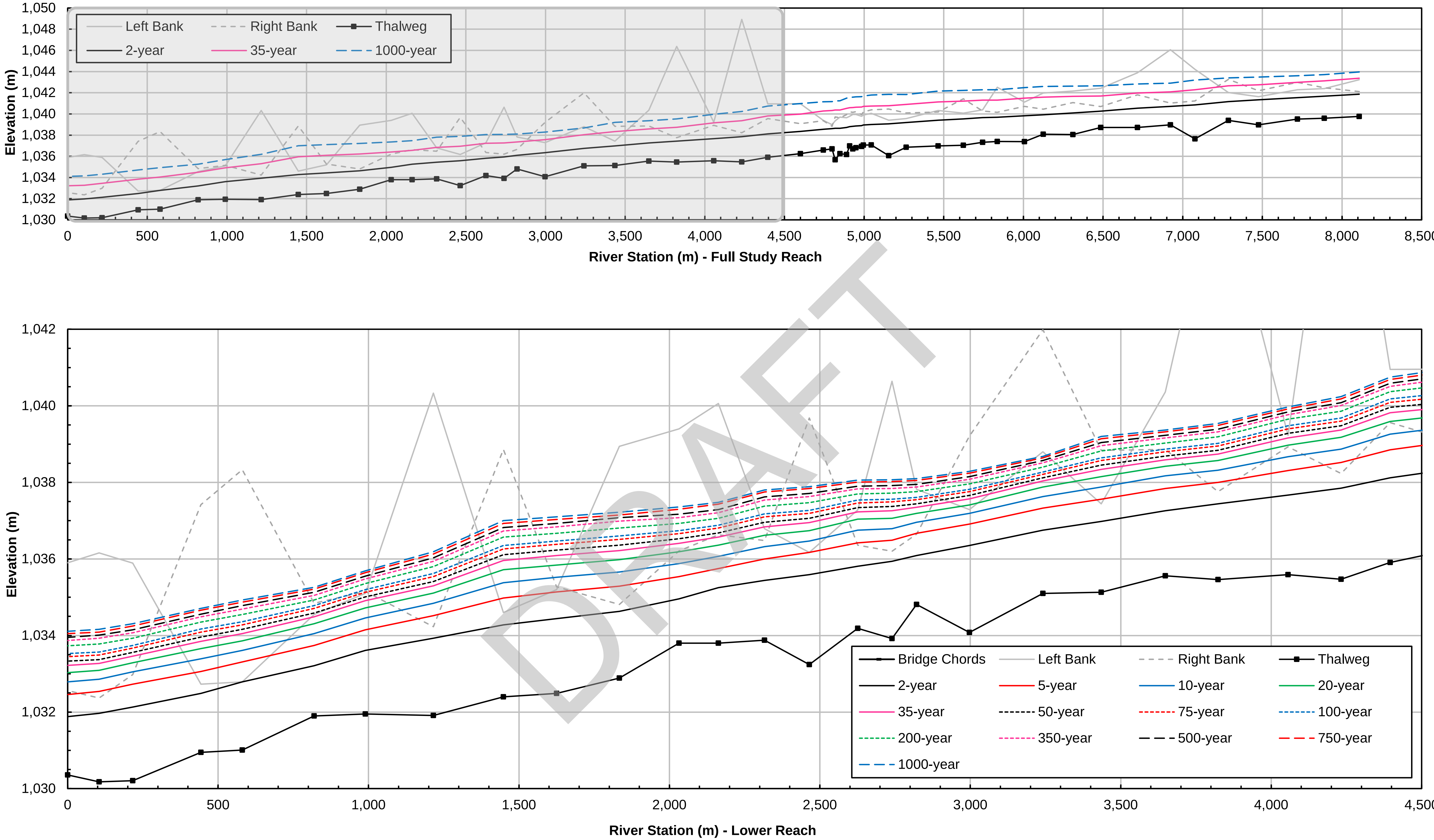
Classification: Public



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Job: 01006666

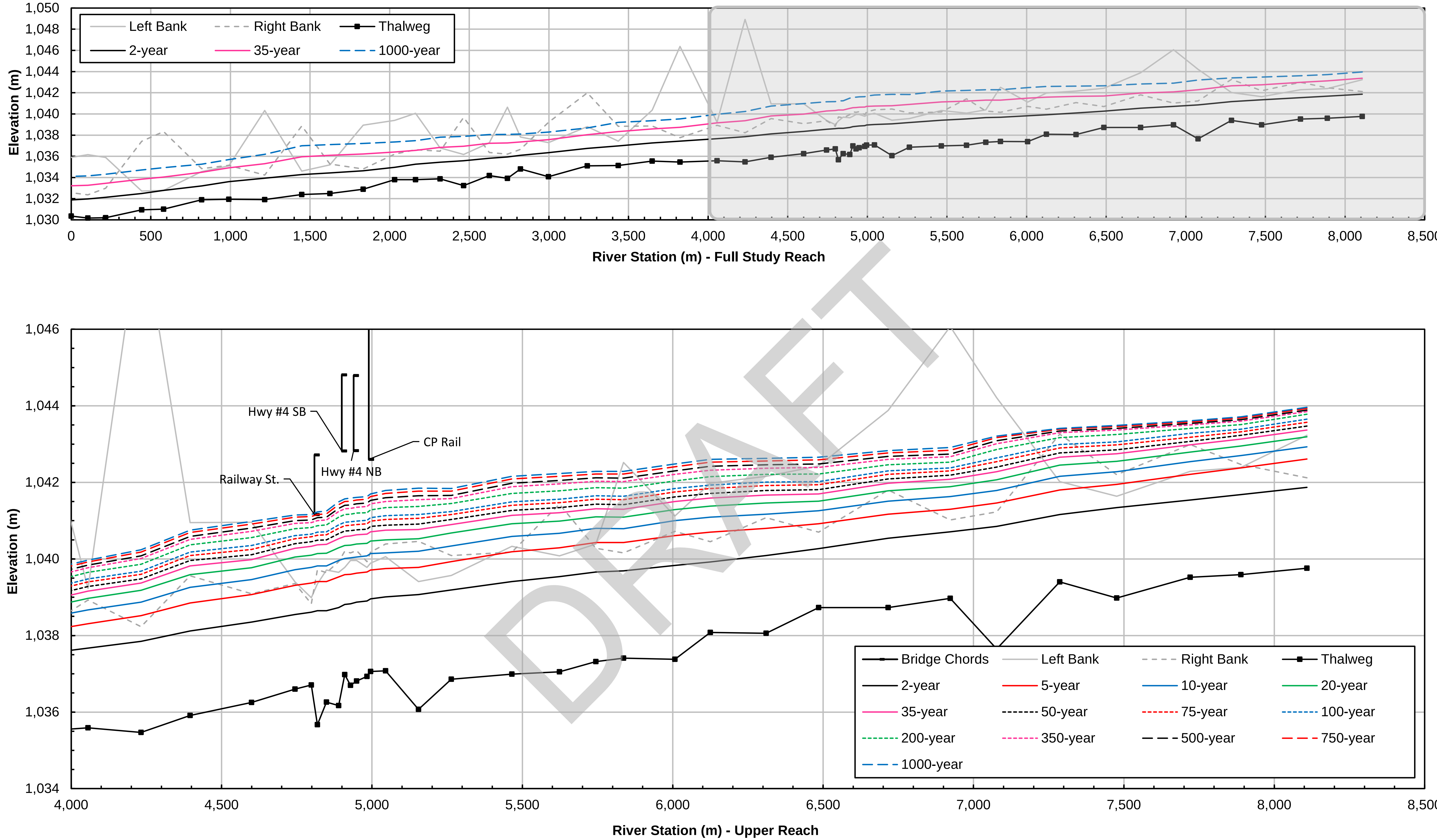
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

COMPUTED FLOOD FREQUENCY PROFILES

FIGURE 12A

Classification: Public



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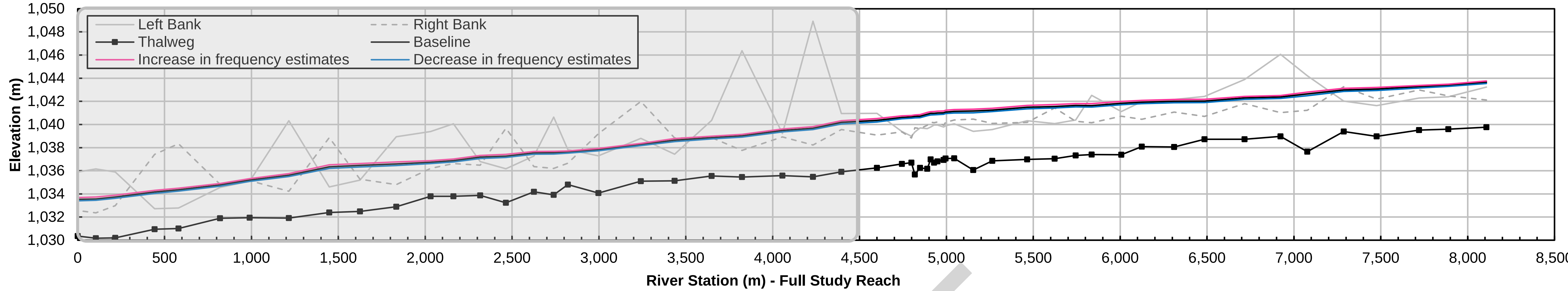
MILK RIVER FLOOD STUDY

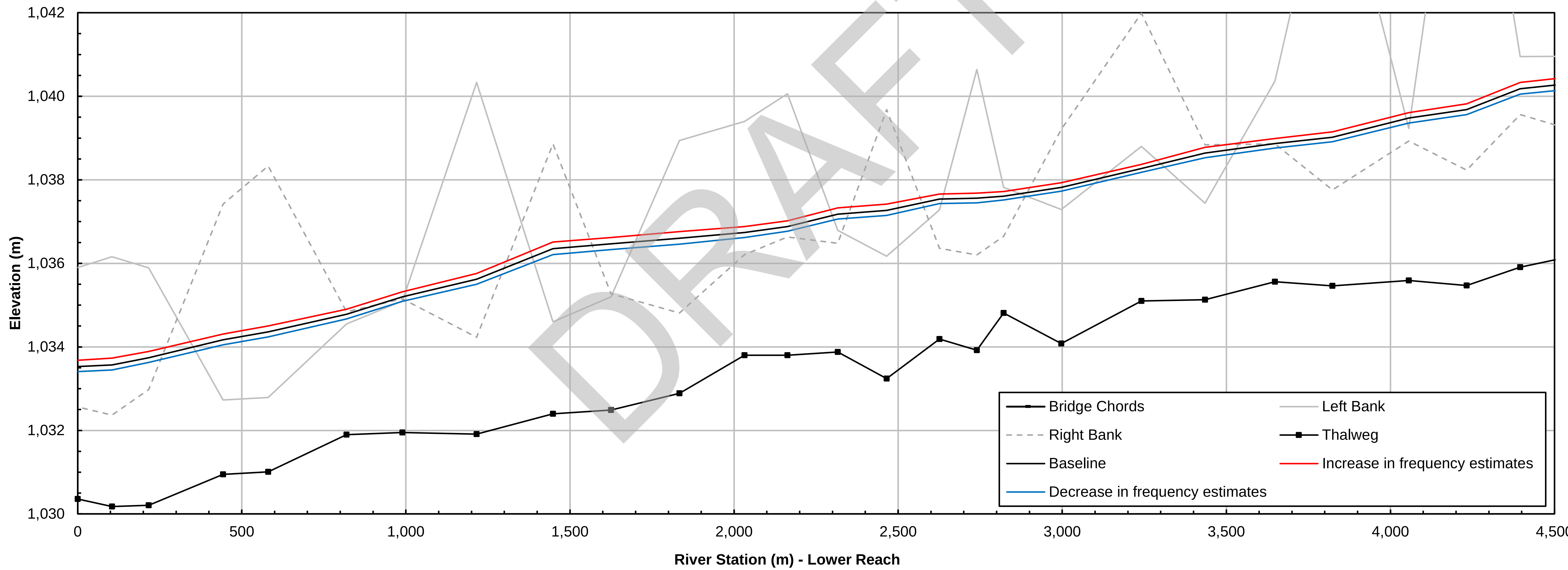
COMPUTED FLOOD FREQUENCY PROFILES

Job: 01006666 | *Date: 14-MAR-2022*

FIGURE 12B

Classification: Public





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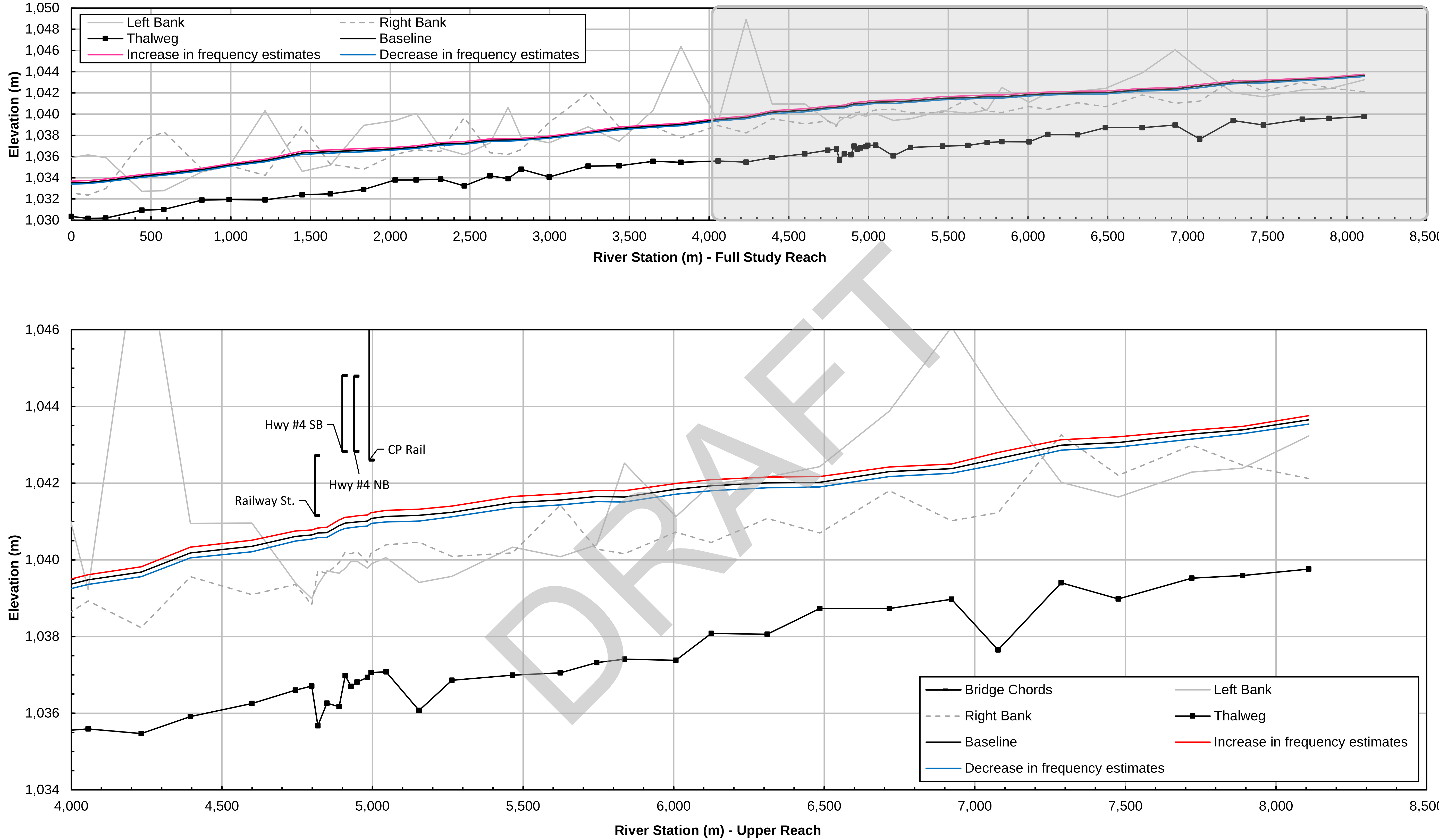
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE FLOOD FREQUENCY ESTIMATES

FIGURE 13A

Classification: Public



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Job: 01006666

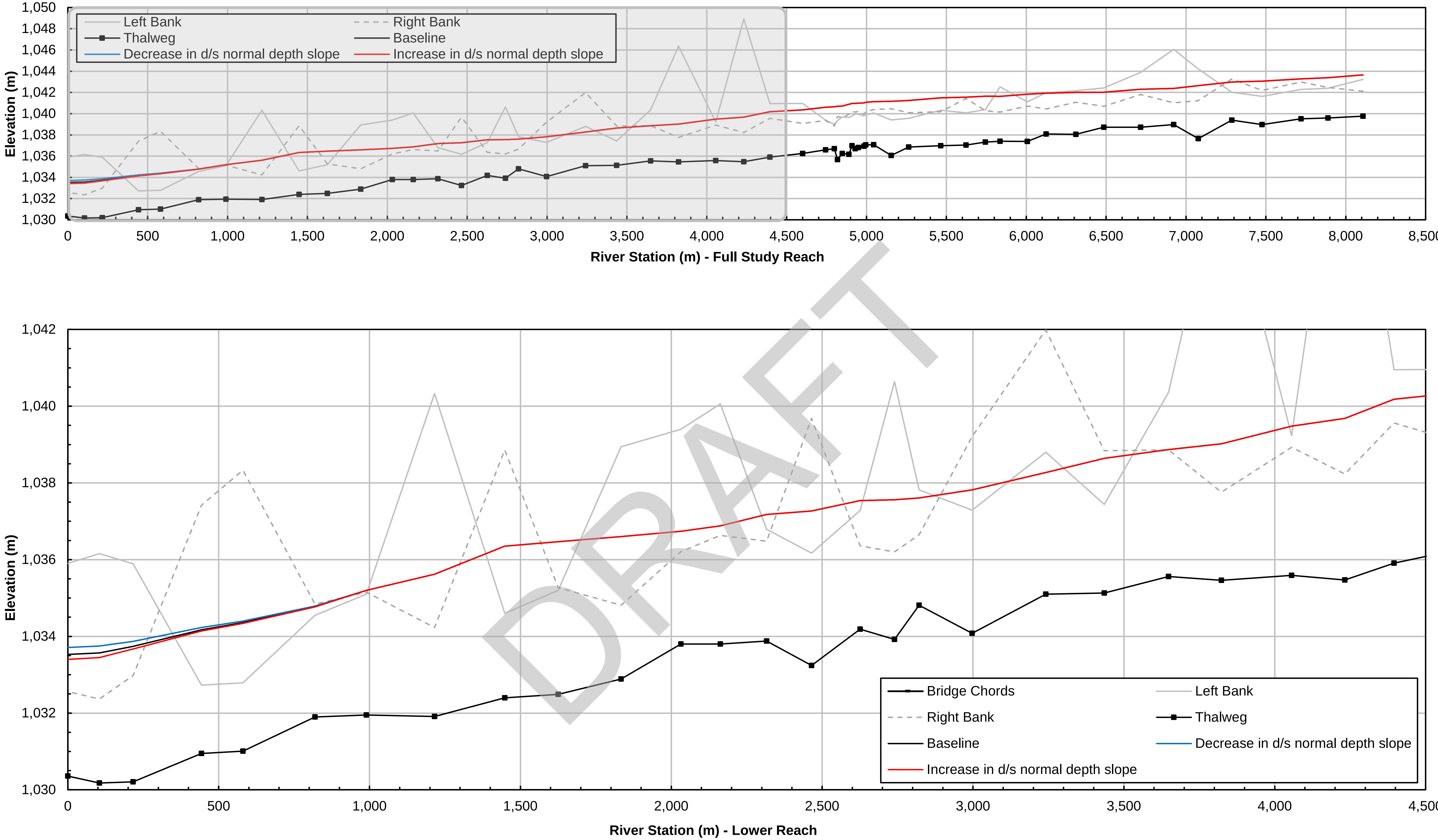
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE FLOOD FREQUENCY ESTIMATES

FIGURE 13B

Classification: Public



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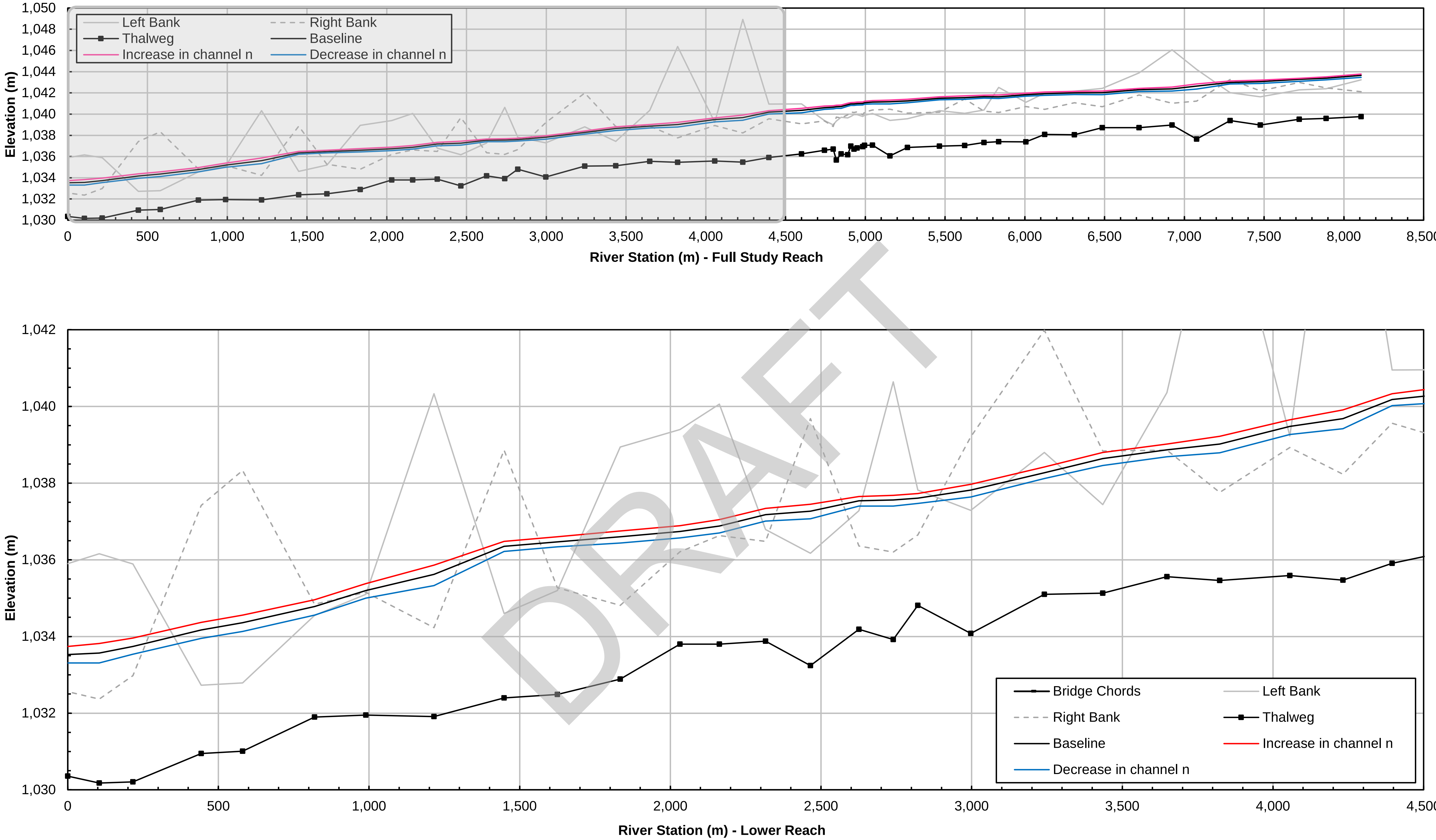
MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE DOWNSTREAM BOUNDARY CONDITION

FIGURE 14

Classification: Public



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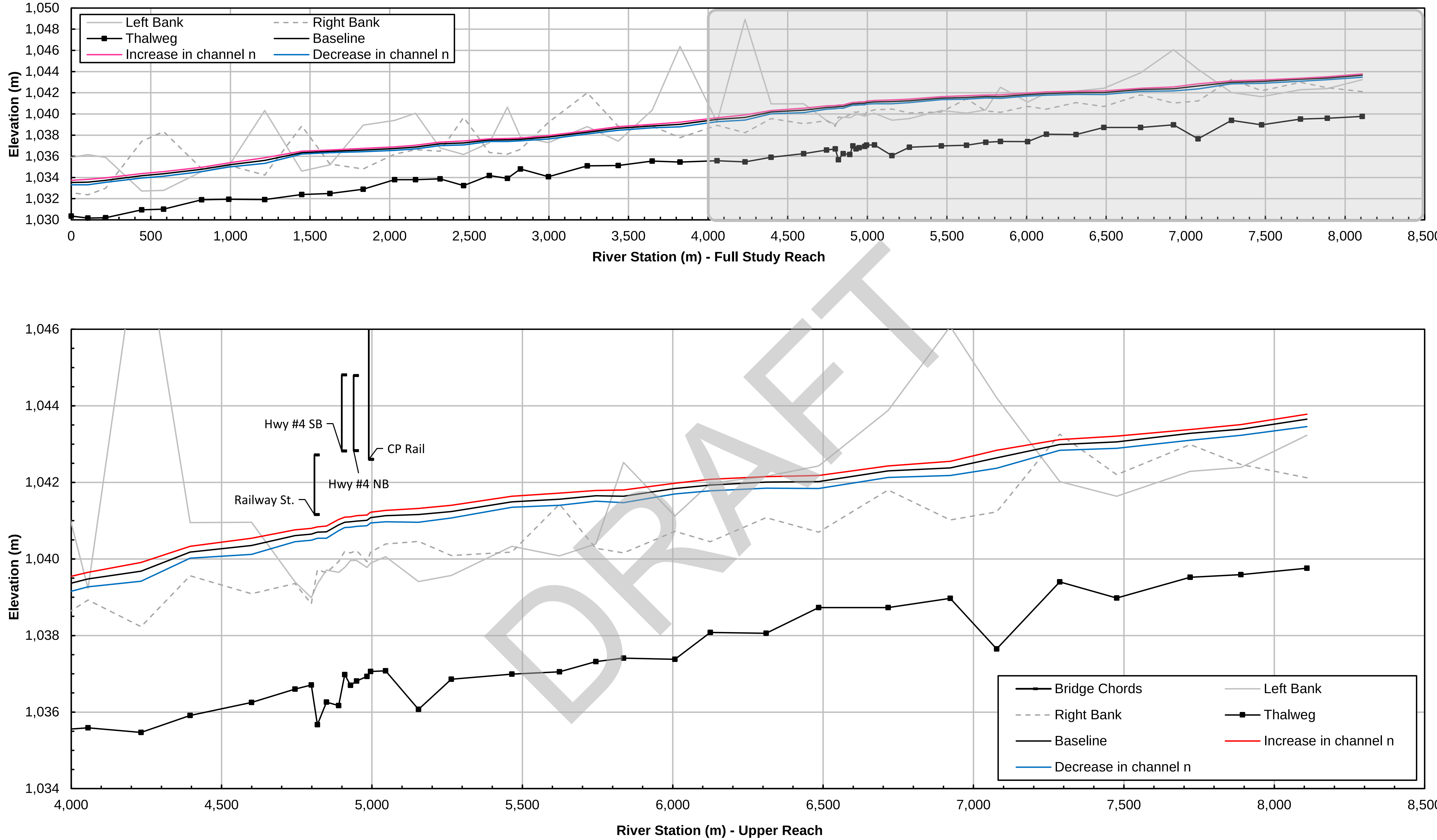
MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE MAIN CHANNEL ROUGHNESS

FIGURE 15A

Classification: Public



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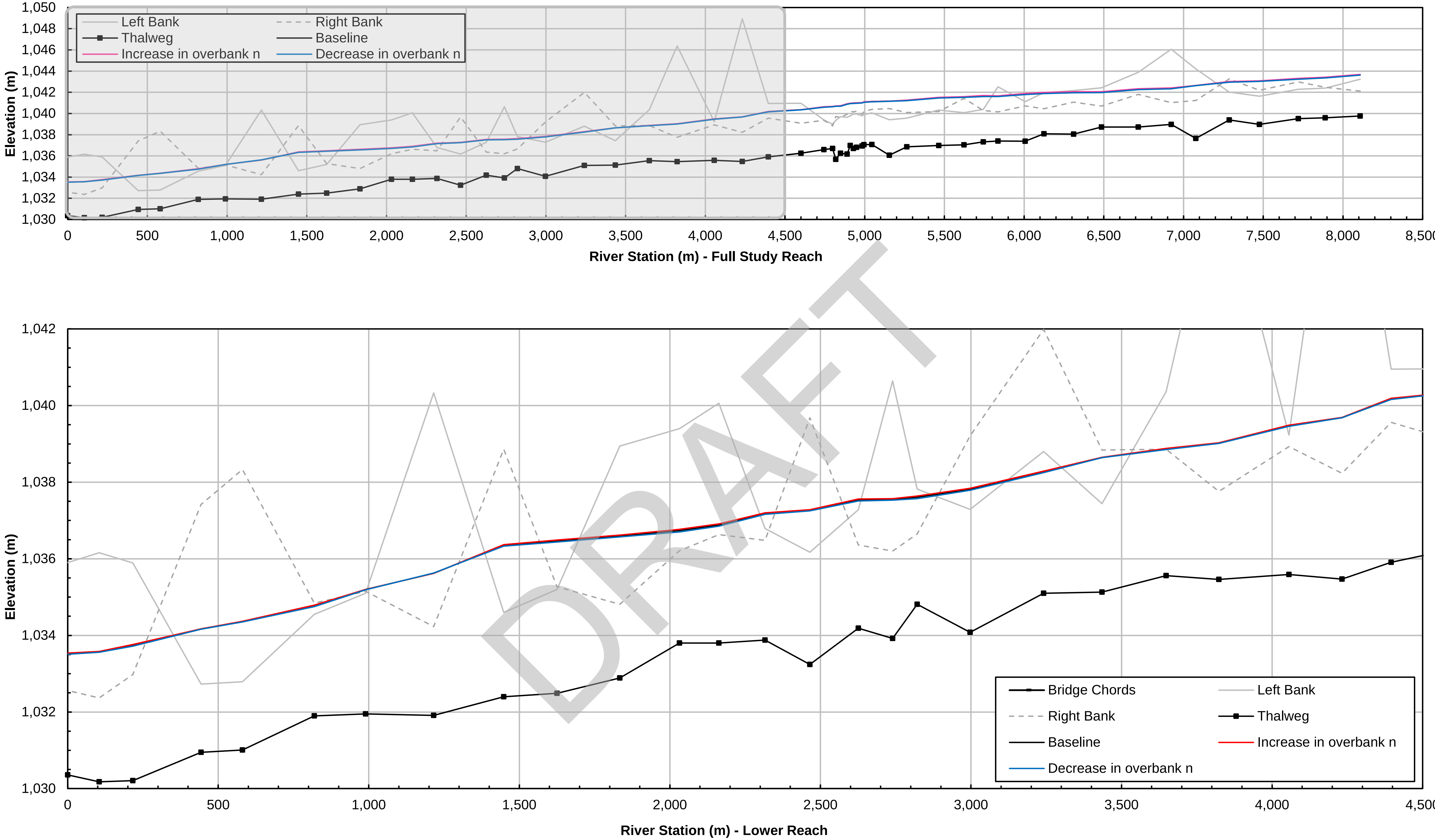
Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE MAIN CHANNEL ROUGHNESS

FIGURE 15B

Classification: Public



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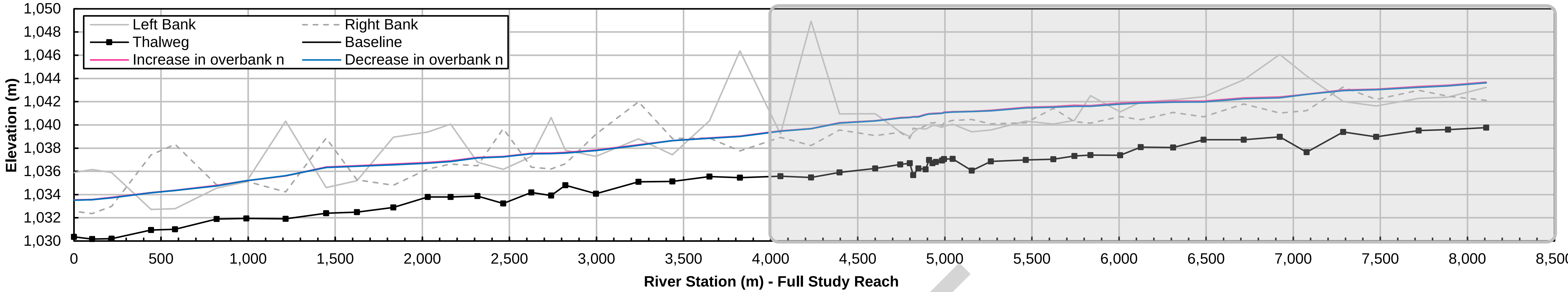
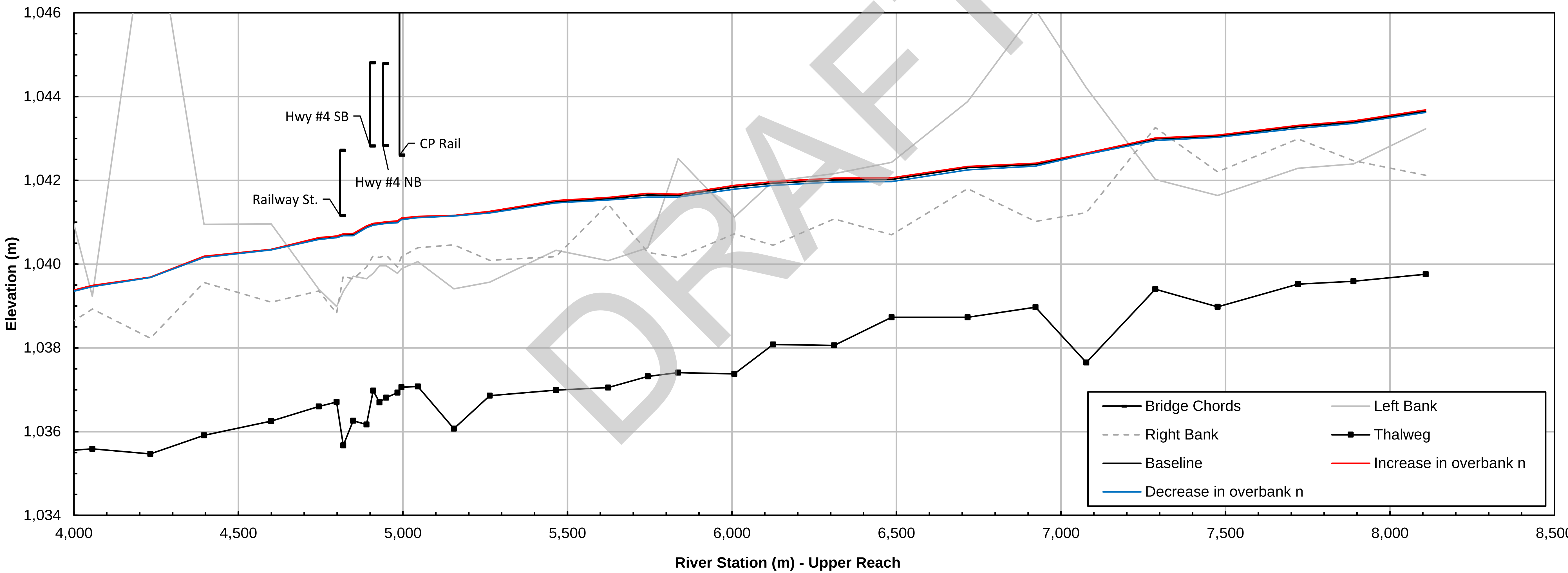
MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE OVERBANK ROUGHNESS

FIGURE 16A

Classification: Public





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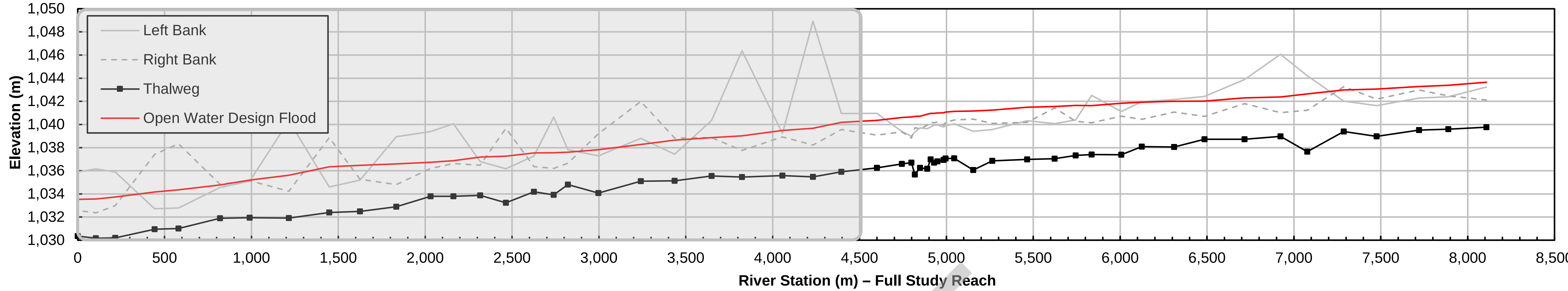
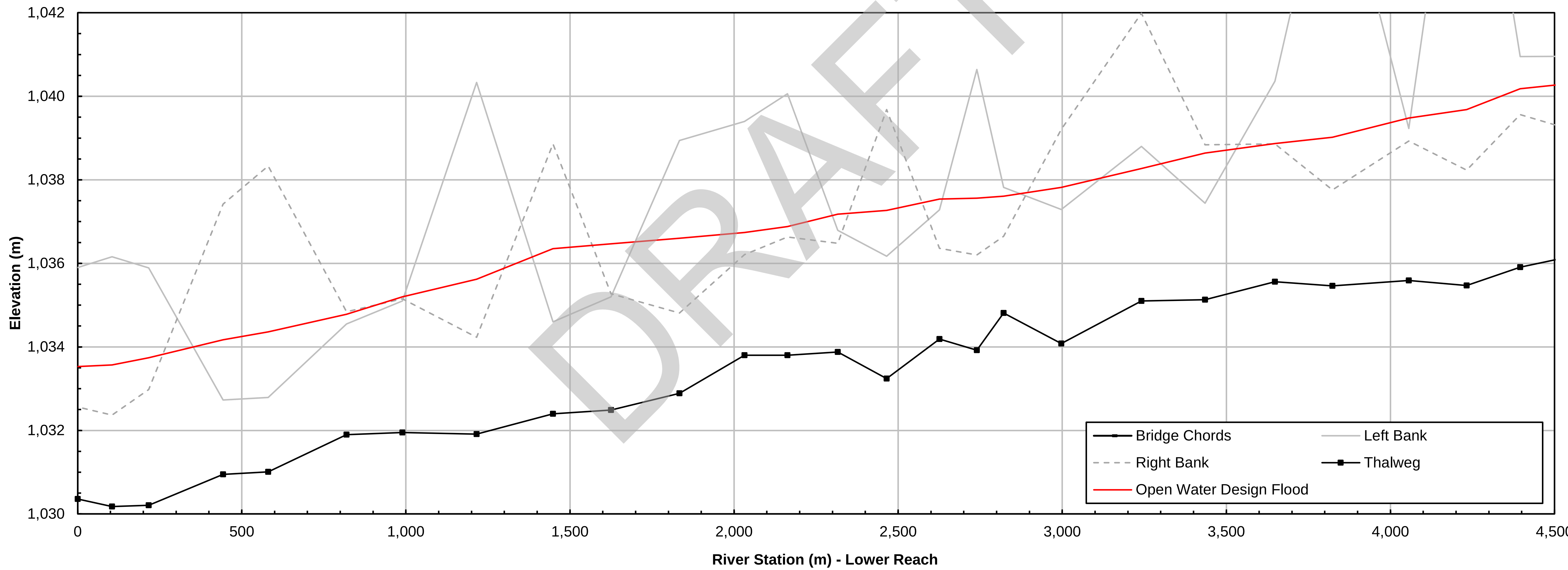
MILK RIVER FLOOD STUDY

SENSITIVITY OF COMPUTED 100-YEAR WATER SURFACE PROFILE TO CHANGES IN THE OVERBANK ROUGHNESS

FIGURE 16B

Classification: Public





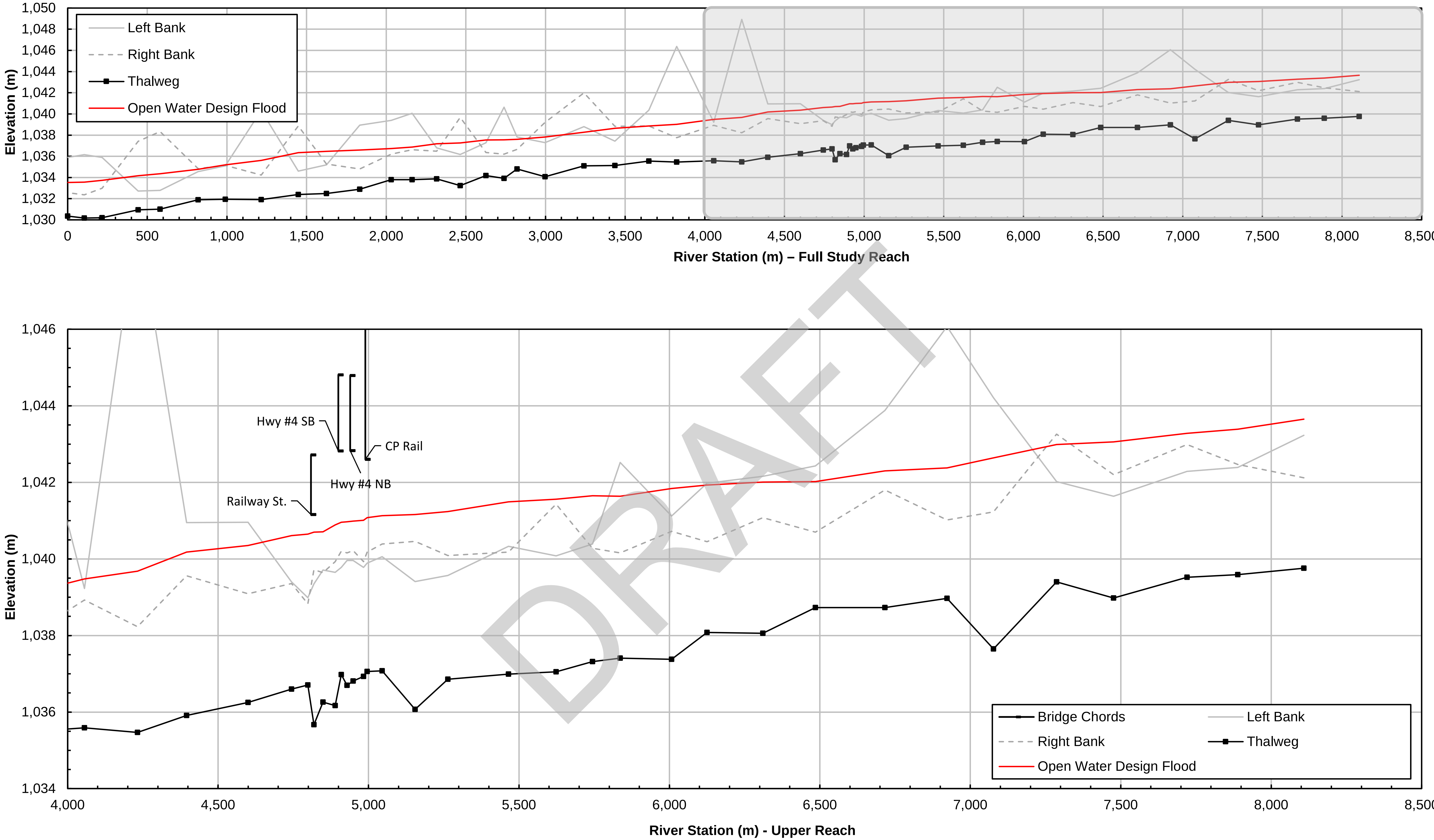
Alberta nhc northwest hydraulic consultants	Job: 01006666	Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

COMPUTED DESIGN FLOOD PROFILE

FIGURE 17A

Classification: Public



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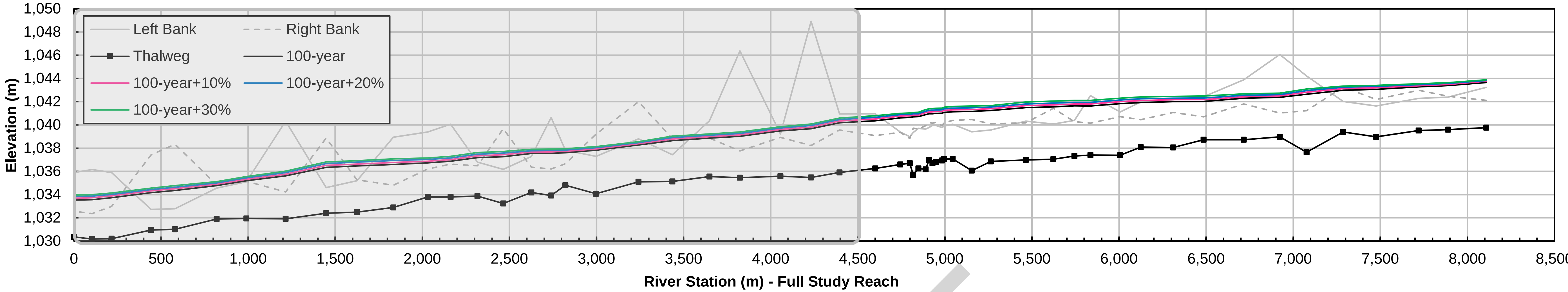
Date: 14-MAR-2022

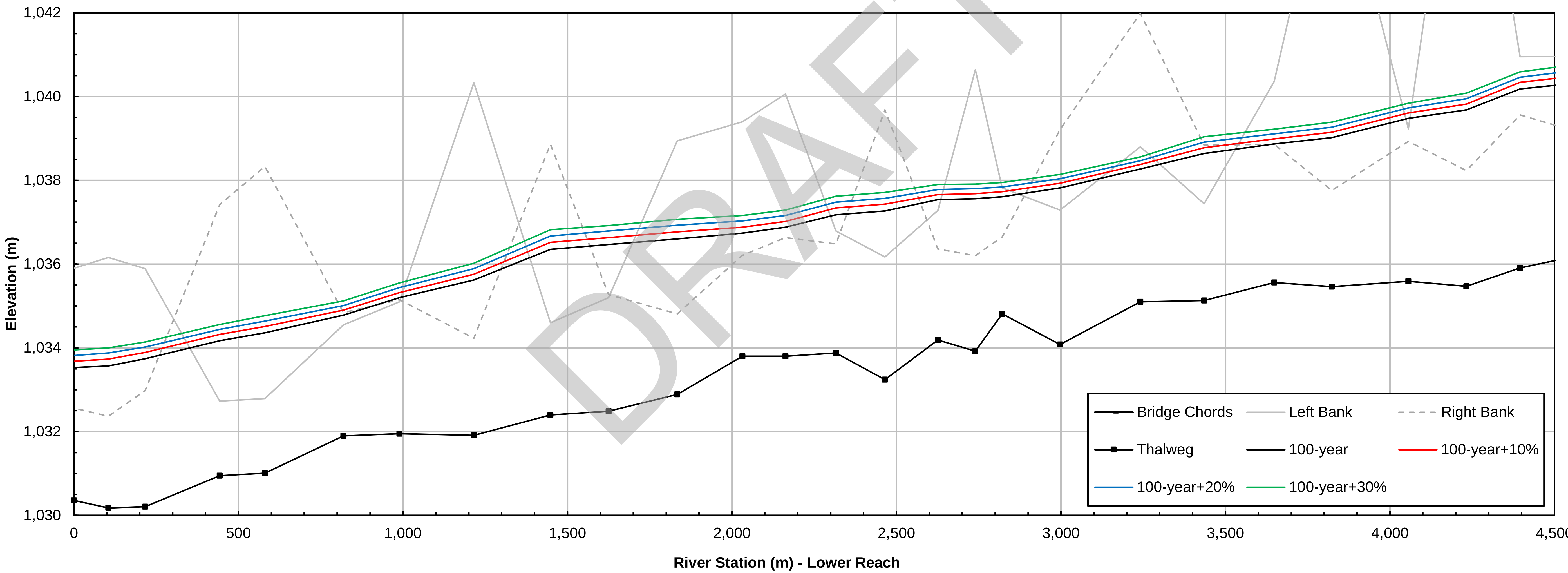
MILK RIVER FLOOD STUDY

COMPUTED DESIGN FLOOD PROFILE

FIGURE 17B

Classification: Public





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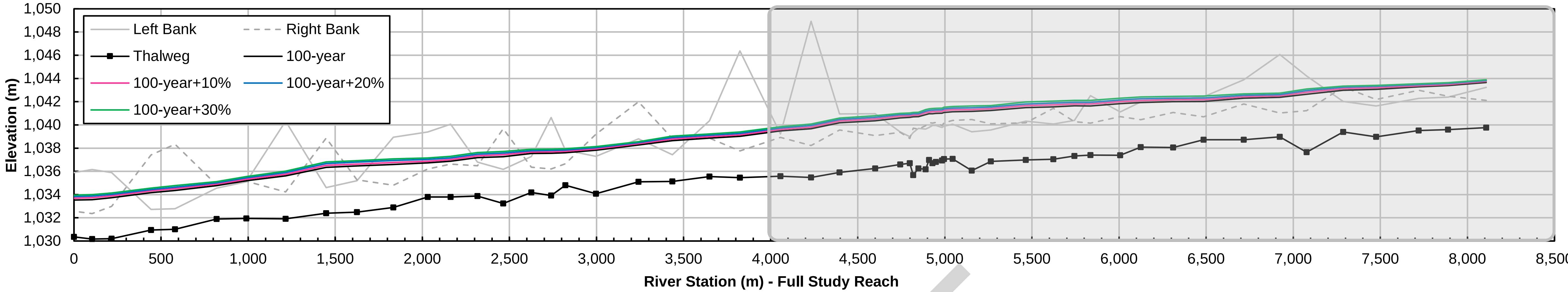
MILK RIVER FLOOD STUDY

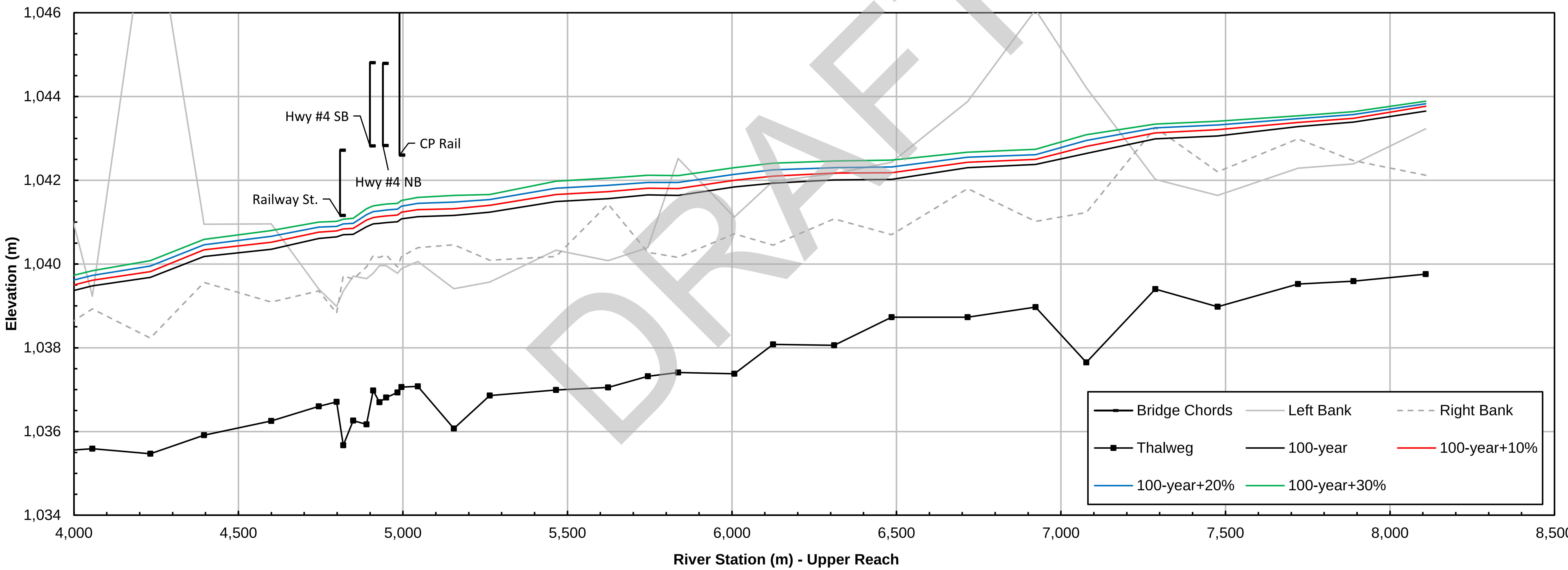
POTENTIAL CLIMATE CHANGE IMPACTS ON DESIGN FLOOD PROFILE

Job: 01006666 | *Date: 14-MAR-2022*

FIGURE 18A

Classification: Public





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Job: 01006666

Date: 14-MAR-2022

MILK RIVER FLOOD STUDY

POTENTIAL CLIMATE CHANGE IMPACTS ON DESIGN FLOOD PROFILE

FIGURE 18B

Classification: Public

APPENDIX A

HYDRAULIC STRUCTURE DETAILS

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Bridge Description

Name:	CP Railway Bridge	**Bridge File No.:**	BF81890
River:	Milk River	**River Station (m):**	4,989.40

Geometry

Span (m):	84.9 m	**Minimum High Chord (m):**	1046.02 m
Width (m):	5.5 m	**Minimum Low Chord (m):**	1042.60 m
Pier Type:	Concrete	**No. of Piers:**	1
Pier Shape:	Triangular nose (90^o)	**Pier Width (m):**	Varies (1.8 m – 2.4 m)

Photo(s)

Looking upstream face of the bridge

Looking at bridge pier from upstream side and left bank

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Classification: Public

Bridge Description

Name:	Highway 4 SBL Bridge	**Bridge File No.:**	BF1426
River:	Milk River	**River Station (m):**	4,938.90

Geometry

Span (m):	81.8 m	**Minimum High Chord (m):**	1044.79 m
Width (m):	13.6 m	**Minimum Low Chord (m):**	1042.83 m
Pier Type:	Concrete	**No. of Piers:**	1
Pier Shape:	Triangular nose (90^o)	**Pier Width (m):**	Varies (1.4 m – 1.8 m)

Photo(s)

Looking downstream portion of the bridge from left bank

DRAFT

Classification: Public

Bridge Description

Name:	Highway 4 NBL Bridge	**Bridge File No.:**	BF1426
River:	Milk River	**River Station (m):**	4,899.50

Geometry

Span (m):	81.8 m	**Minimum High Chord (m):**	1044.81 m
Width (m):	13.6 m	**Minimum Low Chord (m):**	1042.82 m
Pier Type:	Concrete	**No. of Piers:**	1
Pier Shape:	Triangular nose (90^o)	**Pier Width (m):**	Varies (1.4 m – 1.8 m)

Photo(s)

Looking downstream portion of the bridge from left bank

DRAFT

Classification: Public

Bridge Description

Name:	Railway Street Bridge	**Bridge File No.:**	BF1426
River:	Milk River	**River Station (m):**	4,808.75

Geometry

Span (m):	63.7 m	**Minimum High Chord (m):**	1042.72 m
Width (m):	15.9 m	**Minimum Low Chord (m):**	1041.16 m
Pier Type:	Concrete	**No. of Piers:**	2
Pier Shape:	Elongated Semi Circular	**Pier Width (m):**	0.9

Photo(s)

Looking downstream portion of the bridge from left bank

Looking downstream portion of the bridge from right bank

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Classification: Public

APPENDIX B

REACH-REPRESENTATIVE PHOTOGRAPHS

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Milk River

Milk River (downstream view) from middle of channel near River Station 7,476.10 m (XS-53).

Milk River (downstream view) near left bank near River Station 6,922.70 m (XS-50).

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Classification: Public

Milk River (downstream view) from field on left bank near River Station 6,124.80 m (XS-46).

Milk River (downstream view) over gravel bar near River Station 5,744.30 m (XS-43).

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Classification: Public

Milk River (downstream view) from the Railway Street Bridge in the Town of Milk River near River Station 4,798.50 m (XS-29).

Milk river (upstream view) from middle of channel near River Station 3,435.30 m (XS-21).

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Classification: Public

Milk River (downstream view) from right bank above rock spurs near River Station 3,241.50 (XS-20).

Milk River (upstream view) from top of left bank near River Station 1,833.80 (XS-11).

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Classification: Public

Milk River (upstream view) from middle of channel near River Station 1,625.00 m (XS-10).

Milk River (upstream view) from top of left bank near River Station 104.90 m (XS-02).

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Classification: Public

APPENDIX C

OPEN WATER HYDROLOGY ASSESSMENT MEMORANDUM

DRAFT

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NHC Ref. No. 1006666

MEMORANDUM

Prepared by:	Md Makamum Mahmood	Date:	28 March 2022
Reviewed by:	Gary Van Der Vinne	Client File:	22RSD860
Distribution:	Jim Choles (AEP)		

RE: **Milk River Flood Study**
Open Water Hydrology Assessment

DRAFT

1 INTRODUCTION

In June 2021, Alberta Environment and Parks (AEP) retained Northwest Hydraulic Consultants Ltd. (NHC) to complete a flood study for the Milk River through the Town of Milk River and the County of Warner. The scope of work for this study includes the following major components:

- Survey and Base Data Collection
- Open Water Hydrology Assessment
- Open Water Hydraulic Modelling
- Open Water Flood Inundation Mapping
- Design Flood Hazard Mapping
- Reporting and Documentation

This memorandum presents details of the ***open water hydrology assessment***, for which the primary objective is to develop flood frequency estimates for the Milk River at the Town of Milk River, in support of the hydraulic modelling and flood mapping tasks of the Milk River Flood Study.

2 STUDY AREA

As shown in **Figure 1**, the flood hazard study reach extends along approximately 7.2 km of the Milk River through the Town of Milk River and the County of Warner, extending upstream from the south boundary of SE-22-2-16-W4M to the west boundary of NE-20-2-16-W4M.

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The Water Survey Canada (WSC) gauge Milk River at Milk River (WSC Station 11AA005) is representative of the Milk River flows along the study reach. The gauge is in the middle of the study reach and tributary inflows to this relatively short study reach are limited to local overland runoff that would be negligible in comparison with the gauged Milk River flows. The gauge also provides a long term record of flows. Therefore, the recorded flows at Milk River at Milk River (WSC Station 11AA005) were used to generate flood frequency estimates for the 7.2 km study reach.

3 HYDROLOGIC CHARACTERISTICS

3.1 Basin Settings

The Milk River originates in the Rocky Mountain foothills of northern Montana, flows northeast into Alberta, and then returns to the eastern part of Montana. The total length of the Milk River is approximately 1,173 km and the river basin covers an approximate area of 60,000 km^2 and extends into the Canadian provinces of Alberta and Saskatchewan and the US state of Montana. The Milk River drainage basin within Alberta is approximately 6,700 km^2, which is the smallest of Alberta's seven major river basins. While the river hazard study area is limited to an approximately 7.2 km long sub-reach of the Milk River near the Town of Milk River (**Figure 1**), the open water hydrologic assessment covers the entire contributing drainage basin upstream of the Town of Milk River, an area of approximately 2,720 km^2 (the drainage area for WSC Station 11AA005). A basin map is shown in **Figure 2**.

Flows in the Milk River have been regulated since 1917 by St. Mary Diversion Canal. This canal diverts water from the St. Mary River in northwest Montana into the North Milk River, which joins the Milk River about 30 km upstream of the Town of Milk River. The purpose of the canal is to increase summer flows in the Milk River. Water in the Milk River is primarily used for irrigation, municipality supply and provides recreational opportunities.

3.2 Flood Characteristics

Flows of Milk River at the Town of Milk River have been measured by the WSC at Station 11AA005 since 1909. **Figure 3** shows the 1909-2020 daily flows for this gauge station. The flow records are continuous over the entire period of record, except for 1909, 1910, and first three months of 1911. Annual peak flows on the Milk River more commonly occur in spring (late March to May) due to snowmelt runoff with or without rainfall. Intense summer rainstorm events (June-July) may result in high annual peak flows as well.

The three largest recorded floods occurred at Milk River in 1986, 1975, and 2002. The largest flood on record is the 1986 flood, which occurred in late February. The climate data in the Milk River Basin for the 1986 flood indicates a sudden temperature rise with rainfall, causing significant snowmelt runoff within the basin. The upstream, downstream, and surrounding WSC gauge data responded similarly to the same event, indicating that the peak flow at Milk River was caused by runoff rather than a local ice jam release upstream of the gauge. The 1986 station analysis provided by WSC for the Milk River at Milk River gauge states that the 26 Feb 1986 discharge measurement by WSC was within 4% of the WSC open water rating curve used at that time; therefore, even though there may have been some minor ice affects in the 1986 flood peak estimation, it can be characterized as an open water flood.

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The 1975 and 2002 floods occurred in June and are believed to be due to summer rainstorms.

4 FLOOD FREQUENCY ANALYSIS

4.1 Data Series Preparation

The terms of reference for this study requires flood frequency estimates to be developed for the study reach. The WSC Station Milk River at Milk River (11AA005) provides a long-term (112 years) streamflow record, which can be directly used to develop flood frequency estimates for the study reach. NHC gathered all published hydrometric data, including daily and instantaneous annual peak discharges from WSC. As discussed in Section 4.2, the effect of the St. Mary flow diversion on WSC 11AA005 flows is insignificant, and a single station analysis of this record will be adequate for this study.

Figure 4 and **Table 1** show the annual peak flow series for Milk River at Milk River. While the combined data series spans from 1909 to 2020, instantaneous peaks are not provided in many of the years, and where missing, they are calculated on the basis of the correlation between the instantaneous peak and daily discharges for years when both were measured, as shown in **Figure 5**. **Figure 5** shows two sets of data combined to establish the correlation. The first set represents those years when the WSC reported instantaneous and daily annual peak discharges corresponding to the same flood event. The second set represents those years where the WSC reported instantaneous and daily annual peak discharges do not correspond to the same flood. For those years, the daily peak values corresponding to the instantaneous peak were obtained from the continuous WSC daily data series.

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Table 1: Annual peak instantaneous and daily discharges for Milk River at Milk River

Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on the Same Event of Peak Instantaneous Discharge (m^3/s)	WSC Data Symbol
1909	131.0	May-23				
1910						
1911	**73.1**		58.0	Jun-26		
1912	**53.6**		42.5	Apr-3		
1913	55.2	Apr-14	53.5	Apr-14		
1914	**32.5**		25.8	Apr-6		
1915	**43.8**		34.8	Jun-26		
1916	**127.3**		101.0	Feb-17		B
1917	**118.8**		94.3	Apr-7		
1918	**35.7**		28.3	Mar-28		B
1919	**26.8**		21.3	May-10		A
1920	**105.0**		83.3	Apr-21		A
1921	**57.8**		45.9	Apr-3		B
1922	**68.9**		54.7	Apr-23		A
1923	37.4	Jun-23	36.5	Jun-23		
1924	57.2	Apr-7	52.1	Jun-9	51.8	B
1925	59.5	Mar-30	44.2	Mar-30		B
1926	21.8	Jun-20	19.5	Jun-20		

Classification: Public

Year	Peak Instantaneous Discharge (m³/s)	Date	Peak Daily Discharge (m³/s)	Date	Daily Discharge on the Same Event of Peak Instantaneous Discharge (m³/s)	WSC Data Symbol
1927	247.0	May-22	120.0	May-22		
1928	112.0	Mar-21	89.2	Mar-22		B
1929	55.5	Jun-3	54.4	Jun-3		
1930	79.9	Mar-30	65.7	Mar-30		B
1931	16.1	Jul-3	15.6	Aug-1	15.4	
1932	34.5	May-5	31.7	May-6		
1933	37.7	Apr-24	32.0	Apr-24		
1934	48.7	Jun-9	46.2	Jun-9		
1935	103.0	Apr-17	67.1	Apr-17		
1936	95.1	Apr-11	59.7	Apr-12		
1937	109.0	Jun-14	83.3	Jun-14		
1938	37.7	Apr-12	31.7	May-20	30.6	
1939	24.6	Jun-16	24.3	Jun-17		
1940	22.2	Jul-16	21.4	Jul-28	19.8	
1941	22.5	Jun-6	22.3	Jun-6		
1942	50.4	Apr-3	42.2	Apr-4		
1943	**52.0**		41.3	Apr-4		
1944	18.3	May-21	17.8	May-22		
1945	32.0	Jun-8	31.4	Jun-8		E
1946	22.3	Jun-23	21.4	May-31	21.1	
1947	151.0	Mar-22	89.2	Mar-22		B
1948	174.0	Jun-18	144.0	Jun-18		
1949	31.7	May-21	31.4	May-21		
1950	58.9	Apr-17	47.0	Apr-18		
1951	166.0	Jun-25	120.0	Jun-25		
1952	67.4	Mar-30	62.9	Mar-30		B
1953	204.0	Jun-4	169.0	Jun-4		
1954	65.7	Apr-6	41.9	Apr-18	41.6	B
1955	97.1	May-19	77.3	May-20		
1956	58.9	Jul-4	52.1	Jul-5		
1957	38.2	May-9	37.4	May-9		
1958	62.0	Apr-2	51.3	Apr-5	51.0	
1959	40.5	May-20	38.8	May-20		
1960	82.1	Mar-21	62.3	Mar-21		B
1961	30.3	May-18	28.3	May-18		
1962	31.1	Apr-16	30.3	Apr-16		
1963	**37.0**		29.4	Feb-7		B
1964	230.0	Jun-9	129.0	Jun-9		
1965	64.6	Jun-27	62.6	Apr-8	59.5	
1966	97.4	Jun-5	69.9	Jun-5		
1967	146.0	May-9	118.0	May-9		
1968	49.0	Jun-8	41.1	Jun-9		
1969	114.0	Apr-2	106.0	Apr-2		
1970	47.0	Jun-14	42.2	Jun-15		

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Classification: Public

Year	Peak Instantaneous Discharge (m³/s)	Date	Peak Daily Discharge (m³/s)	Date	Daily Discharge on the Same Event of Peak Instantaneous Discharge (m³/s)	WSC Data Symbol
1971	34.3	Feb-15	33.7	Feb-15		B
1972	132.0	Mar-18	105.0	Mar-17		B
1973	23.5	May-25	23.1	May-26		
1974	50.4	May-1	44.5	May-1		
1975	260.0	Jun-21	207.0	Jun-21		
1976	**43.2**		34.3	Mar-19		
1977	22.4	May-19	22.3	May-19		
1978	**89.2**		70.8	Mar-22		B
1979	**62.7**		49.8	Mar-9		B
1980	60.5	May-27	55.6	May-27		
1981	59.7	May-16	57.6	May-17		
1982	136.0	Apr-14	112.0	Apr-14		A
1983	20.3	Jul-20	19.6	Jul-18	19.6	
1984	23.2	Jun-24	22.2	Jun-24		
1985	32.3	Jun-1	31.1	Jun-1		
1986	279.0	Feb-25	218.0	Feb-26		A
1987	40.5	Apr-6	32.7	Apr-5		
1988	27.7	Apr-9	26.4	Apr-9		
1989	86.8	Mar-27	55.0	Jun-12	36.0	
1990	42.5	May-31	38.7	May-31		
1991	90.5	Jun-22	81.5	Jun-22		
1992	20.2	Jul-25	19.1	Jul-25		
1993	**60.2**		47.8	Mar-25		B
1994	**84.4**		67.0	Mar-4		B
1995	160.0	Jun-8	147.0	Jun-8		
1996	**55.6**		44.1	May-25		
1997	**228.1**		181.0	Mar-20		B
1998	64.4	Jul-4	42.2	Jul-4		
1999	24.6	Jun-5	23.8	Jun-5		
2000	**23.2**		18.4	May-12		
2001	33.8	Apr-26	26.8	Apr-26		
2002	251.0	Jun-10	222.0	Jun-11		
2003	**94.5**		75.0	Mar-16		B
2004	24.3	May-24	23.6	May-24		
2005	78.6	Jun-8	63.1	Jun-8		
2006	37.6	Apr-7	35.6	Apr-7		
2007	**37.8**		30.0	Mar-8		B
2008	69.8	Jun-13	65.4	Jun-13		
2009	29.4	May-6	27.4	May-6		
2010	193.0	Jun-18	155.0	Jun-18		
2011	95.5	Jun-9	89.5	Jun-10		
2012	33.1	Apr-29	30.1	Apr-29		
2013	25.6	Jun-22	23.7	Jun-22		
2014	145.0	Jun-20	123.0	Jun-20		

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Year	Peak Instantaneous Discharge (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date	Daily Discharge on the Same Event of Peak Instantaneous Discharge (m^3/s)	WSC Data Symbol
2015	31.1	Jun-4	30.1	Jun-4		
2016	19.7	Aug-8	18.2	Jul-16	17.9	
2017	**<u>103.3</u>**		82.0	Mar-16		B
2018	54.6	Apr-16	43.7	Apr-16		
2019	**<u>59.5</u>**		47.2	Mar-24		B
2020	40.6	Apr-23	36.5	Apr-23		

Notes:

1. No peak instantaneous and peak daily discharge was reported for 1910 as WSC did not publish any peak values for that year, and the WSC daily data is discontinuous for that year as well.
2. The bolded and underlined values are based on the relationship $Q_i=1.26Q_d$ established in **Figure 5**.
3. Daily discharge on the same event of peak instantaneous discharge is reported in the table for those years where the WSC reported instantaneous and daily annual peak discharges do not correspond to the same flood.
4. WSC data symbol “A” stands for Partial Day, “B” stands for Ice Conditions, and “E stands for Estimate. Details about the WSC data symbol can be found https://wateroffice.ec.gc.ca/contactus/faq_e.html
5. For 1920, 1982, and 1986, the WSC published peak annual daily discharge has an “A” data symbol, which means partial measurements on those days. Reviewing the daily data series for the years as mentioned earlier (1920, 1982, and 1986) revealed daily data marked as “B” (Ice Conditions) for the same event just before 1 or 2 days of the peak instantaneous occurred. This indicates that there might be possible ice effects on the reported peak of 1920, 1982, and 1986 though they are not marked with a data symbol of “B” (Ice Conditions).

Table 1 also identifies the years when the peak discharge measurement was most likely having some ice affects. NHC identified 26 of those years among 112 years of record by reviewing the WSC flag “B” (which denotes ice effects on the water level) in the daily and peak published data. For the same peak discharge, the ice affected water level would be higher than that of the non-affected water level. All the potential ice affected peak annual discharges were included in the data series for the open water frequency analysis since open water represents the minimum water level that could occur for these discharges. This approach is consistent with what NHC has done for other flood studies and with the previous two hydrology assessments for Milk River (AENV, 2001 and AENV, 2013).

4.2 Flow Naturalization

Flows from the North Milk River (which is the major tributary of the Milk River) were affected by the St. Mary diversion since 1917. The North Milk River’s drainage area accounts for about 40% of the total drainage area of the Milk River at Milk River. The St. Mary diversion flows are recorded at the St. Mary Canal at St. Mary Crossing gauge (WSC Station 05AE029). The diversion flows typically go up to about 17-19 m3/s in the growing season (April to October) and are zero in the winter months.

Several previous studies have demonstrated that the effect of diversion through the St. Mary diversion canal on Milk River flood peaks is insignificant. These studies include McLean and Beckstead (1981), Bradley and Smith (1984), AENV (2001), and AENV (2013). McLean and Beckstead (1981) and Bradley and Smith (1984) showed, by comparing pre- and post-diversion flows, that there was little change in the mean annual flood flow on the mainstem Milk River following diversion. AEP hydrology assessments completed in 2001 (AENV,2001) and 2013 (AENV, 2013) include assertions that, historically, typical diversions are negligible when compared to Milk River flood flows and that the recorded Milk River

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annual peak flood series is an acceptable approximation of the natural flood series for the purpose of flood frequency analysis.

NHC also did an assessment to validate the assumptions presented in several previous studies. The naturalized daily flows for Milk River at Milk River could be approximated by subtracting the St. Mary diversion flows (WSC Station 05AE029) from the Milk River gauge data (WSC Station 11AA005). As shown in **Figure 6**, there is little difference between the naturalized annual peak daily flows and the affected annual peak daily flows for Milk River at Milk River, especially for higher flows. Note that Milk River's estimated naturalized daily flows did not consider any routing effect between the St. Mary Diversion Canal and Milk River at Milk River. If the routing effect were considered, the change in the daily flows on the Milk River at Milk River following diversion could be even smaller.

Therefore, it can conclude that the effect of St. Mary Canal diversion flows on the annual peak daily flows along the Milk River study reach is small; therefore, no flow naturalization is required.

4.3 Single Station Frequency Analysis

A single-station frequency analysis was performed on the Milk River peak instantaneous discharges shown in **Table 1**. The frequency analysis was conducted using the USACE HEC-SSP (version 2.1) flood frequency program and a spreadsheet model developed by NHC. In accordance with the Hydrologic and Hydraulic Guidelines for Flood Hazard Area Delineation by AENV (2008) and Guidelines on Flood Frequency Analysis by Alberta Transportation (AT, 2001), 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 (W) 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 positioning formula was used to plot data points for visualization purposes. **Table 2** provides a summary of the statistical parameters for the Milk River flow series.

Table 2: Summary of statistical parameters of annual instantaneous peak discharge series for Milk River at Milk River

Parameter	Annual Instantaneous Peak Flow Series (1909, and 1911-2020)
Years of record	111
Mean (m^3/s)	74.46
Median (m^3/s)	55.57
Standard deviation (m^3/s)	58.84
Coefficient of variation	0.79
Skew coefficient (minimum, maximum, actual)	1.58, 2.02, 1.69

The USGS “Guidelines for Determining Flood Frequency” Bulletin 17C (USGS, 2018) was also reviewed and considered for the study. The USGS Guidelines provide a framework primarily intended to standardize the methods to account for historic flood information, zero flows or low outliers, and high outliers, and methods to estimate population parameters. They use the LP3 as the base method for flood frequencies with the parameters being estimated from the Expected Moments Algorithm (EMA).

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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 squares method (Kite, 1977). This method is based on the sum of squared errors (*SSE*) calculated by:

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

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 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, visual assessment and Bayesian concepts as it is on the statistical ranking result.

Table 3 shows the ranking of the frequency distributions based on D_n and *SSE* values. The P3 distribution has the lowest *SSE* and relatively small D_n values and is ranked the best in the combined ranking. The LN distribution also produces relatively small D_n and *SSE* values and ranked second in the combined ranking. The Bulletin 17C distribution produces the lowest D_n values; so, despite the higher *SSE* values, it ranked third in the combined ranking. These three distributions are compared in **Figure 7**. The other ranking distributions are shown graphically in **Appendix A**.

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Table 3: Goodness-of-fit comparison for probability distributions for Milk River at Milk River

Distribution	D_n	Normalized *SSE* ($Q_{pm} = 74.46\ m^3/s$)	Rank by D_n	Rank by *SSE*	Combined Ranking
Normal (N)	0.181	0.358	9	9	9
Log-normal (LN)	0.065	0.153	3	3	2
Three parameter log-normal (LN3)	0.117	0.155	5	4	4
Pearson III (P3)	0.108	0.122	4	1	1
Log-Pearson III (LP3)	0.052	0.227	1	8	4
Gumbel (G)	0.139	0.197	8	6	8
Generalized extreme value (GEV)	0.117	0.167	5	5	7
Weibull (W)	0.136	0.140	7	2	4
Bulletin 17C	0.052	0.225	1	7	3

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From a visual inspection of **Figure 7**, it is clear that the LN and Bulletin 17C curves are identical in the lower part and provide the best fit for the data points at the shorter return periods. The two curves diverge when the return period exceeds about 10 years. Its middle part, between 5 and 15-year return periods, does not fit the data as well as the P3 curve. The lower part of P3 curve does not fit the data as well as LN and Bulletin 17C curves. For relatively higher return periods, the Bulletin 17C appears to fit better the flood events between 20 and 50-year return periods, while the P3 curve tends to fit better the two largest events (1986 and 1975).

The previous AEP hydrology assessments completed in 2001 (AENV, 2001) and 2013 (AENV, 2013) adopted P3 and Weibull distributions respectively for their flood frequency estimates. These two distributions are compared in **Figure 8** for this study**.** As shown in **Figure 8**, the P3 and Weibull curves are nearly identical for the lower part, but the P3 distribution results in greater flood peaks for return periods longer than 50 years. The P3 distribution produces conservatively higher flood peaks compared to the Weibull distribution, and it ranked better in the combined ranking (**Table 3**)**.**

Based on the above comparisons, it is recommended that the P3 distribution be used herein to describe the flood peaks for Milk River at Milk River. The adopted P3 curve is shown in **Figure 9** along with its 95% confidence limits.

5 FLOOD FREQUENCY ESTIMATES

The flood frequency estimates for Milk River at Milk River (WSC Station 11AA005) are presented in **Table 4**. They are based on the Pearson type III (P3) distribution, which provide the best representation of the flood peaks among all assessed distributions. The flood frequency estimates were also compared

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with values from previous studies in **Table 4**. The differences between the current and previous flood frequency estimates are insignificant.

Table 4: Flood frequency estimates for Milk River at Milk River (WSC Station 11AA005) and compared with previous studies

Return Period (Years)	Annual Probability of Exceedance (%)	Peak Instantaneous Discharge (m^3/s)		AENV (2001)	AENV (2013)
		Value	95% Confidence Limit		
1000	0.1	397	364 - 439	428	404
750	0.13	383	351 - 422		
500	0.2	361	331 - 398	387	369
350	0.29	343	315 - 378		
200	0.5	313	288 - 345	332	321
100	1	277	255 - 304	291	284
75	1.3	262	241 - 287		
50	2	240	221 - 263	249	247
35	2.9	221	204 - 242		
20	5	190	176 - 208	194	196
10	10	152	141 - 166	153	157
5	20	113	104 - 124	111	116
2	50	59	49 - 68	57	59

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6 CLIMATE CHANGE COMMENTARY

This section summarizes a qualitative interpretation of climate and hydrologic projections obtained from the scientific literature that would be pertinent to evaluating future changes in flood hazards in the study area.

U.S. Department of the Interior Bureau of Reclamation and State of Montana Department of Natural Resources and Conservation (2012) assessed the effects of climate change on the Milk River Basin. Some of the key findings of the study are noted as follows:

- Temperature in the Milk River basin is likely to follow a warming trend in the future. Temperature increases over the Milk River basin could range from 1.6°C to 2.3°C for a projection period centered on 2050 and for a climate change scenario representing the central tendency group of projected changes.

- The selected General Circulation Models (GCMs) differ in their predictions of changes to annual precipitation in the Milk River basin, but most of the predictions were for the overall wetter conditions in the basins, with increasing year-to-year variability. The change in precipitation

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could range from approximately 2% to 12% for a projection period centered on 2050 and for a climate change scenario representing the central tendency group of projected changes.

- Projected changes in annual natural streamflow volumes vary across the Milk River basin and among different climate scenarios. Overall, streamflow for the region is projected to increase for most climate change scenarios for a projection period centered on 2050. For the central tendency scenario, the median streamflow of the mouth of the Milk River is expected to increase about 3%. Although streamflow increases are expected under most scenarios for most areas in the Milk River Basin, the upper areas of the Milk River basin are expected to produce somewhat less runoff. An earlier shift in runoff timing is also projected.

Poitras et al. (2011) investigated projected changes in average and extreme streamflows of ten major river basins across western Canada. The streamflows were derived from climate simulations performed with the fourth generation of the Canadian Regional Climate Model (CRCM) forced with the A2 emission scenario (which is the higher end of the emission scenarios projected to result in warming by approximately 3.4°C by 2100). Though the investigation does not cover the Milk River Basin, it will give a general idea about the impacts of climate change in Canadian rivers. Mean annual flows are projected to increase in all basins, consistent with what the U.S. Department of the Interior Bureau of Reclamation and State of Montana Department of Natural Resources and Conservation (2012) predicted for the Milk River Basin.

More recently, Gizaw (2017) assessed possible changes to extreme precipitation in Southern Alberta River basins using six extreme climate indices based on two downscaled climate scenarios. The results suggest that more frequent and severe intensive storm events may impact Southern Alberta between May and August in the 2050s and 2080s, which implies the increasing flood risk along the Milk River Basin in the future.

In summary, most of the scientific literature indicates increased temperature and precipitation in the Milk River basin. Climate change has the potential to affect the timing and volume of flows in the Milk River. Greater variability of streamflow in the basin is anticipated, with increased peak streamflow during wetter years than in the past and disproportionally less runoff in the drier years. An earlier shift of spring freshet timing is expected because of warmer air temperature. Overall, there is insufficient information to be able to identify all the linkages between precipitation and runoff to make any forecasts about how climate change might affect flood peaks. Given the small change in median flows predicted and the lack of any significant trends in historical peak flows, the most judicious approach would be to assume no changes to flood peaks for the study area over the next number of decades. This is consistent with the conclusions of the Intergovernmental Panel on Climate Change – that at present, there is low confidence in global climate model predictions of changes in flood magnitudes due to limited evidence (Jiménez et al., 2014). In general, increased precipitation may lead to higher flood peaks due to increased precipitation intensity, but this will be mitigated by reduced snowpack and drier antecedent moisture conditions due to higher temperatures. Loss of tree cover and soil changes associated with the beetle infestation, wildfires, and changing land use could also contribute to higher runoff volumes and peaks – possibly even having a greater impact than the changing climate.

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8 CLOSURE

This document has been prepared by Northwest Hydraulic Consultants Ltd. (NHC) in accordance with generally accepted engineering practices, for the benefit of Alberta Environment and Parks for specific application to the Milk River Flood Study in Alberta. The information and data contained herein represent the best professional judgment of NHC, based on the knowledge and information available to NHC at the time of preparation.

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Sincerely,

Northwest Hydraulic Consultants Ltd.

Prepared by:

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Project Engineer

Reviewed by:

Gary Van Der Vinne, MSc, PEng
Principal

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Figures

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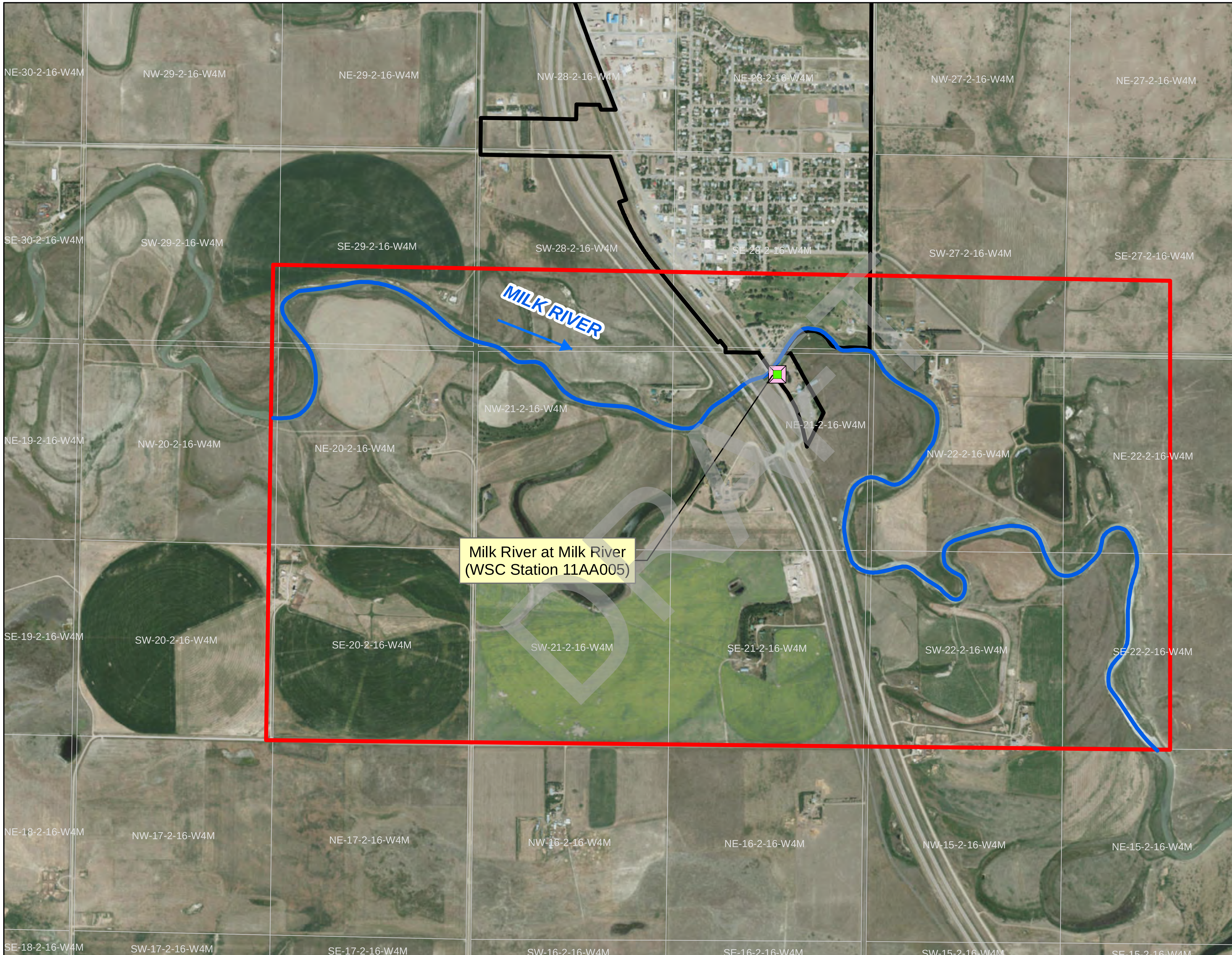

Alberta

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Legend

- FLOOD FREQUENCY ESTIMATE LOCATION
- WSC STATION 11AA005
- STUDY REACH
- FLOOD STUDY AREA
- TOWN OF MILK RIVER
- ATS QUARTER SECTION BOUNDARY

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:15,000

0 0.3 0.6 KM

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

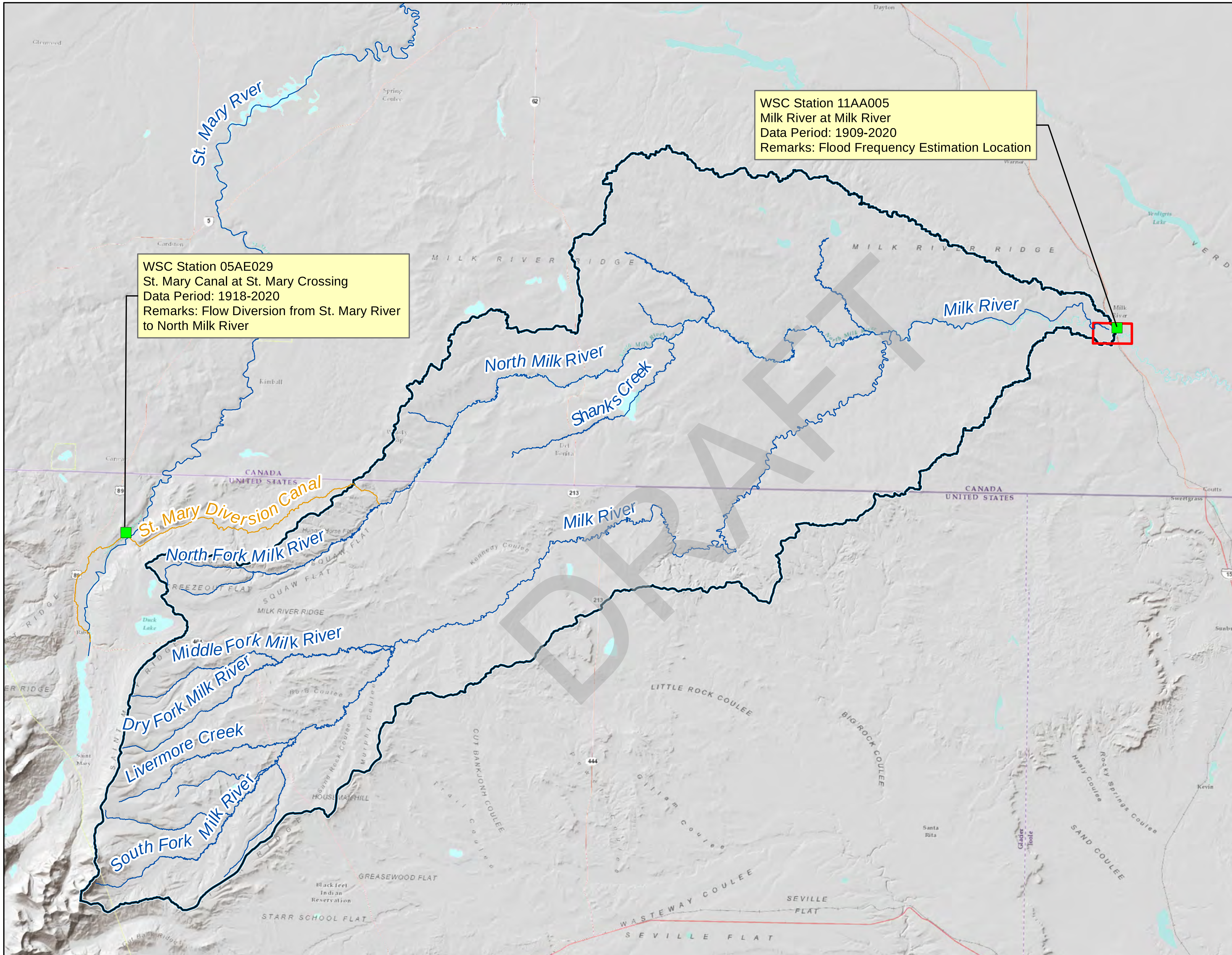
Job: 1006666	*Date: 08-JUL-2021*

MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

FLOOD STUDY REACH AND FLOOD FREQUENCY ESTIMATE LOCATION

FIGURE 1

REH, P:\1_Projects (Active)\1006666 Milk River Flood Study\03 Calculations\01_Hydrology\GIS\1006666_OWH_Figure 1_Study_Reach_FF_Estimate_Location.mxd



Alberta

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Legend

- WSC STATION (SELECTED)
- FLOOD STUDY AREA
- MILK RIVER BASIN

DATA SOURCES: Basemap from Esri & NRCAN.

SCALE - 1:350,000

0 5 10 KM

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

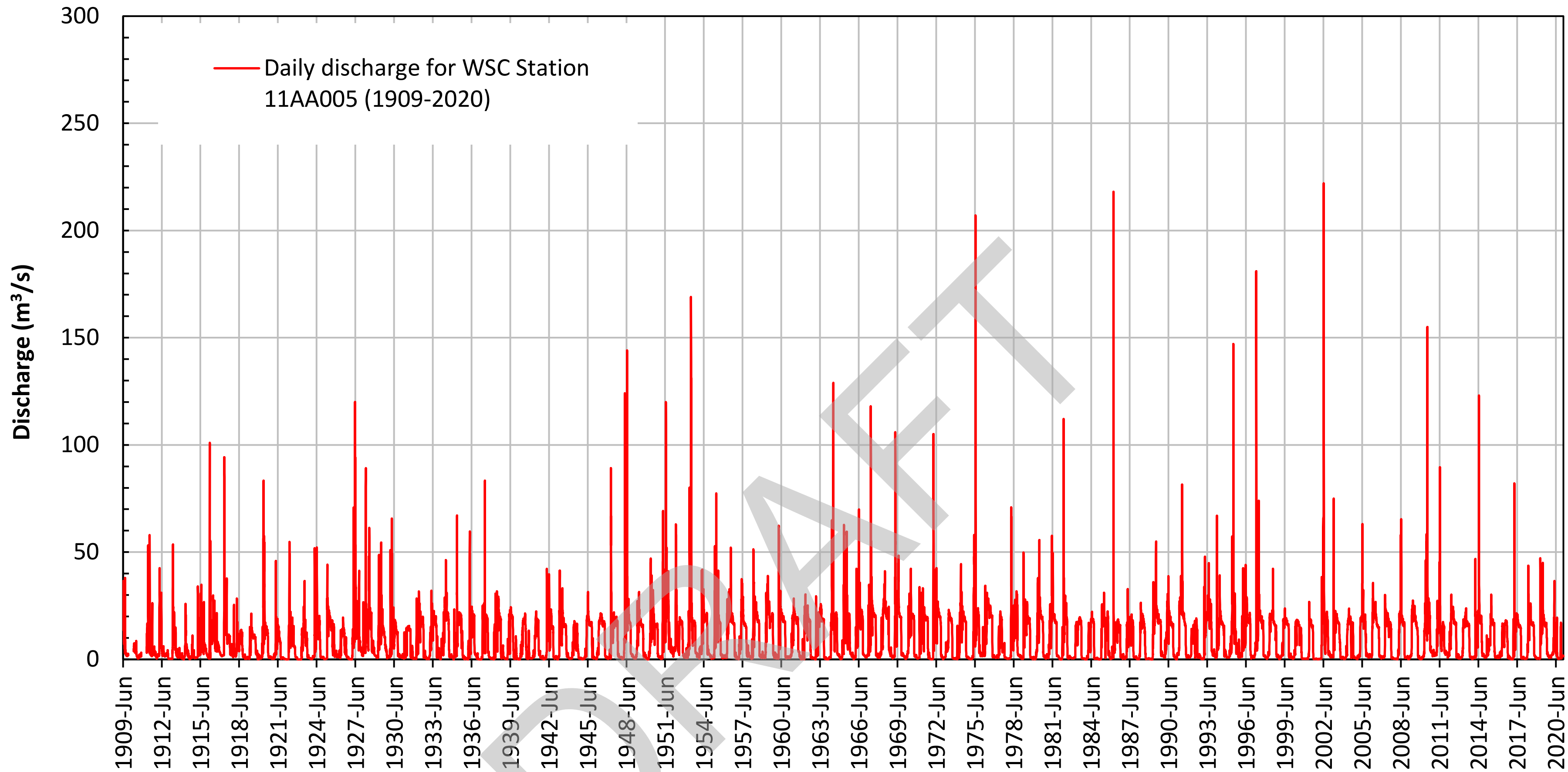
Job: 1006666 | *Date: 06-AUG-2021*

MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

BASIN OVERVIEW

FIGURE 2

Classification: Public



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SCALE – AS SHOWN

Coordinate System:
Units: As Shown

Job: 1006666

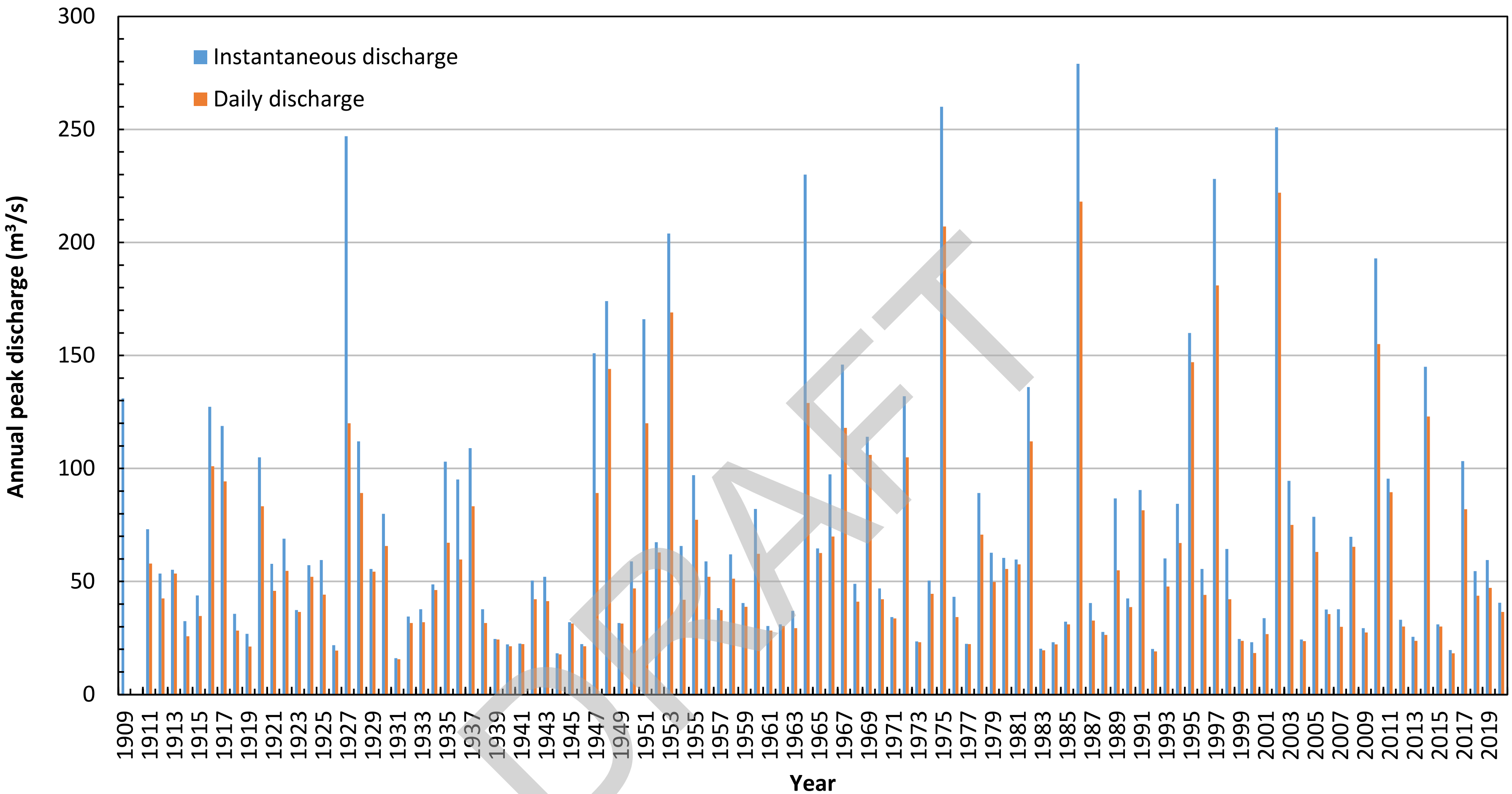
Date: 05-AUG-2021

MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

RECORDED DAILY FLOWS FOR MILK RIVER AT MILK RIVER

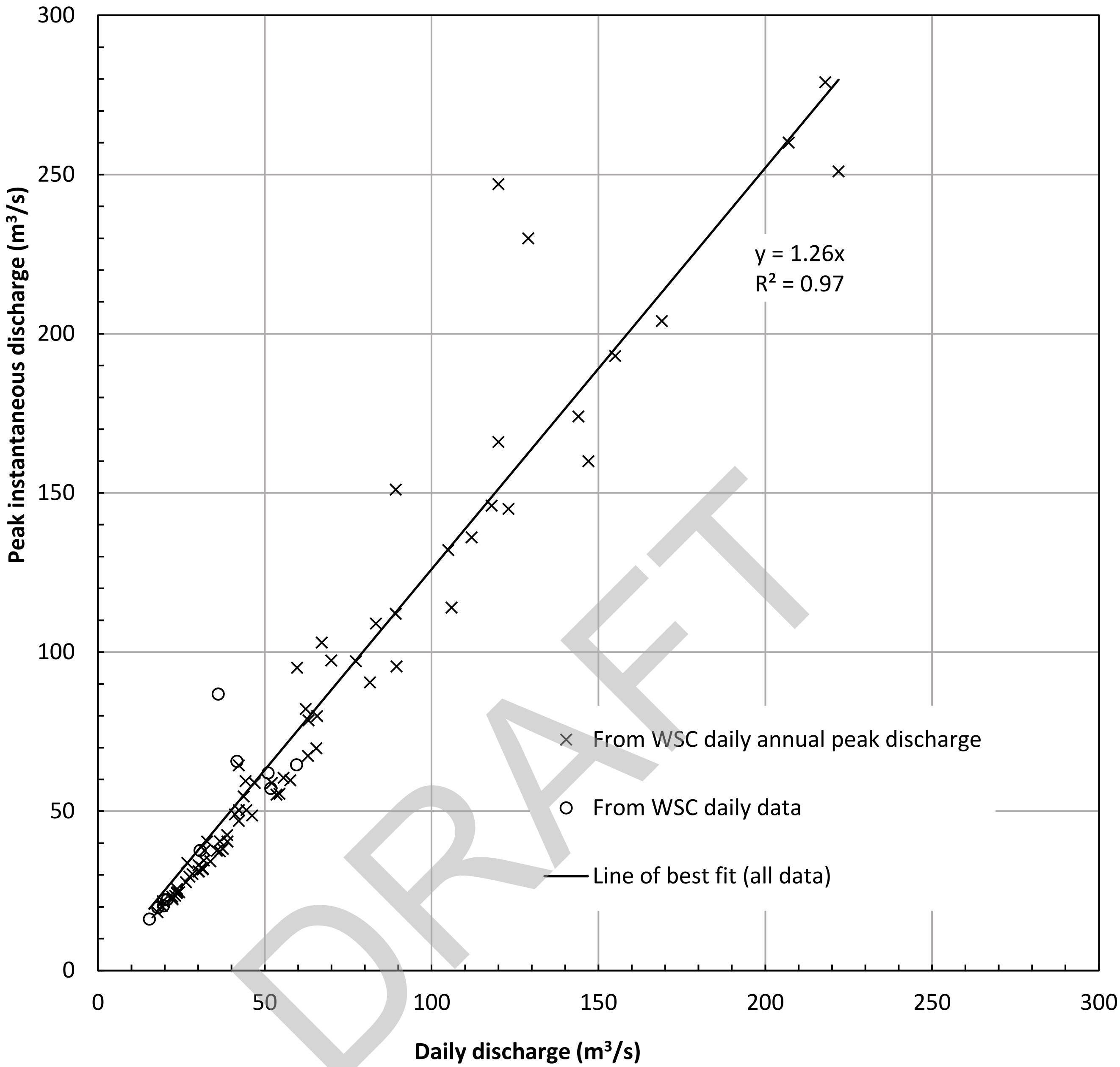
FIGURE 3

Classification: Public



Alberta	SCALE – AS SHOWN	*MILK RIVER FLOOD STUDY* *OPEN WATER HYDROLOGY ASSESSMENT*
nhc northwest hydraulic consultants	Coordinate System: Units: As Shown	*ANNUAL PEAK FLOWS FOR MILK RIVER AT MILK RIVER*
	Job: 1006666 | *Date: 05-AUG-2021*	*FIGURE 4*

Classification: Public



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Units: As Shown

Job: 1006666

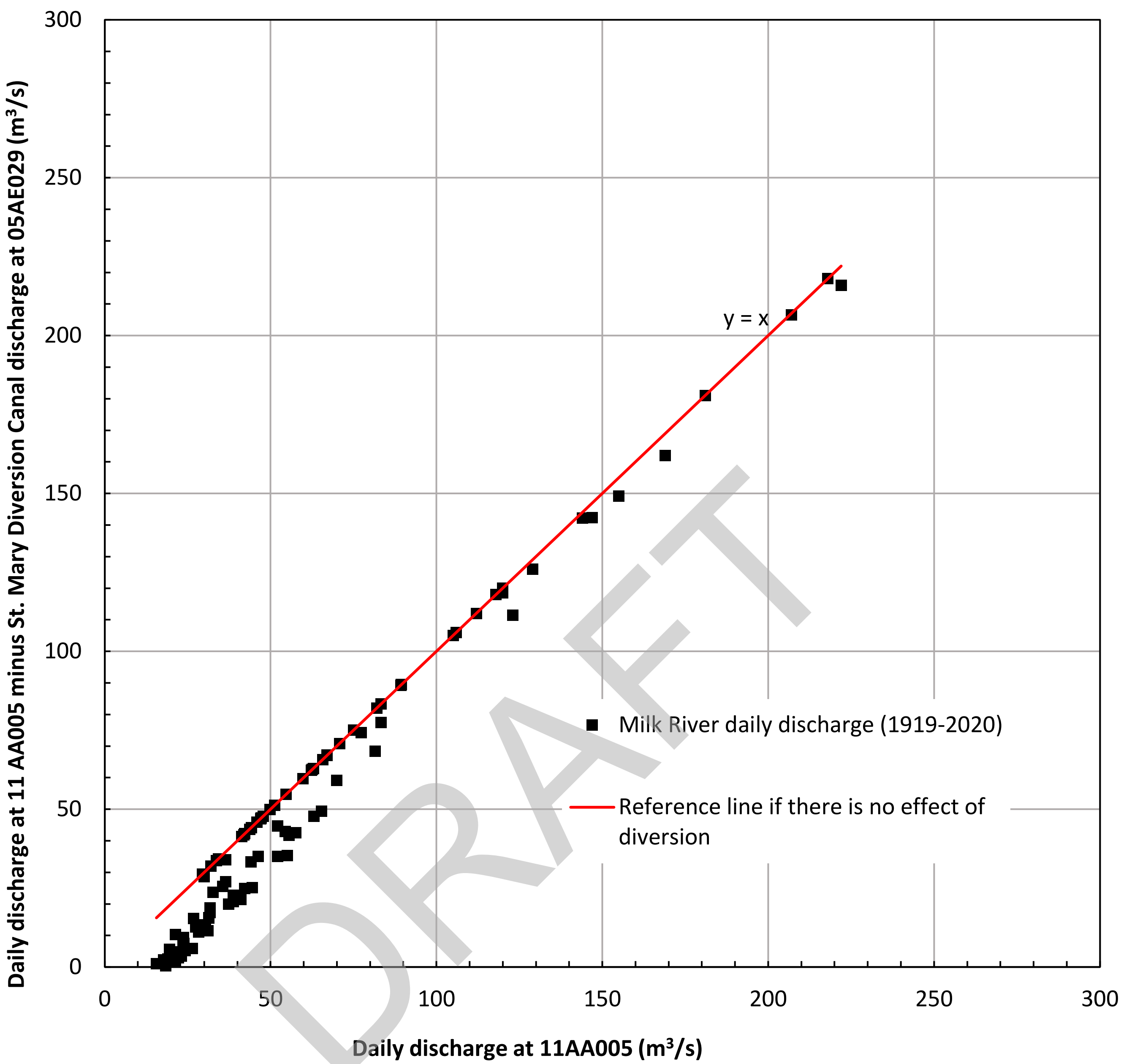
Date: 30-AUG-2021

MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

MILK RIVER AT MILK RIVER
PEAK INSTANTANEOUS TO DAILY DISCHARGE RATIO

FIGURE 5

Classification: Public



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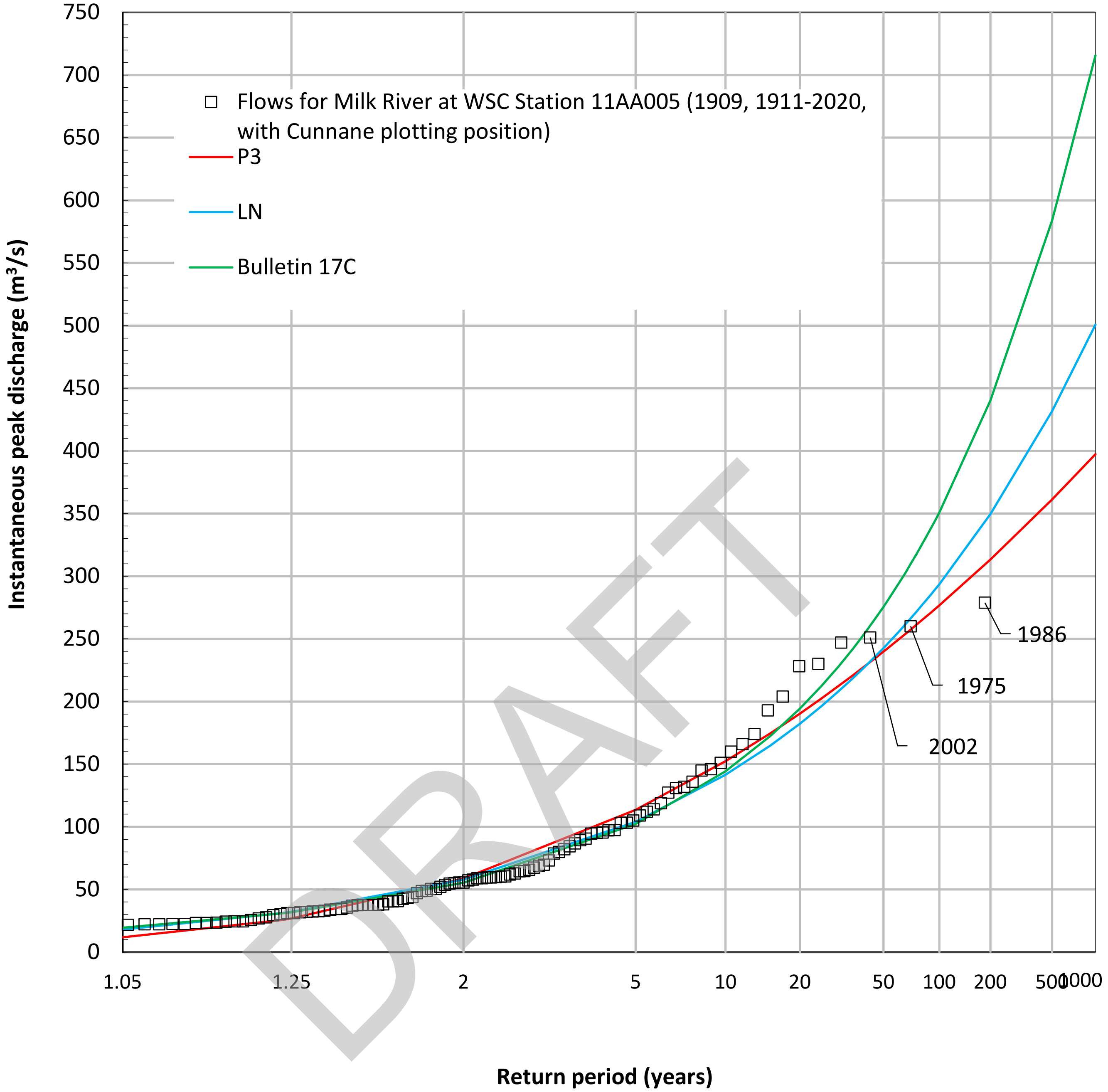
nhc northwest hydraulic consultants	Coordinate System: Units: As Shown	
	Job: 1006666 / *Date: 30-AUG-2021*	*FIGURE 6*

Classification: Public



SCALE – AS SHOWN

Coordinate System:
Units: As Shown

MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

COMPARISON OF FLOOD FREQUENCY CURVES FOR MILK RIVER AT MILK RIVER

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FIGURE 7

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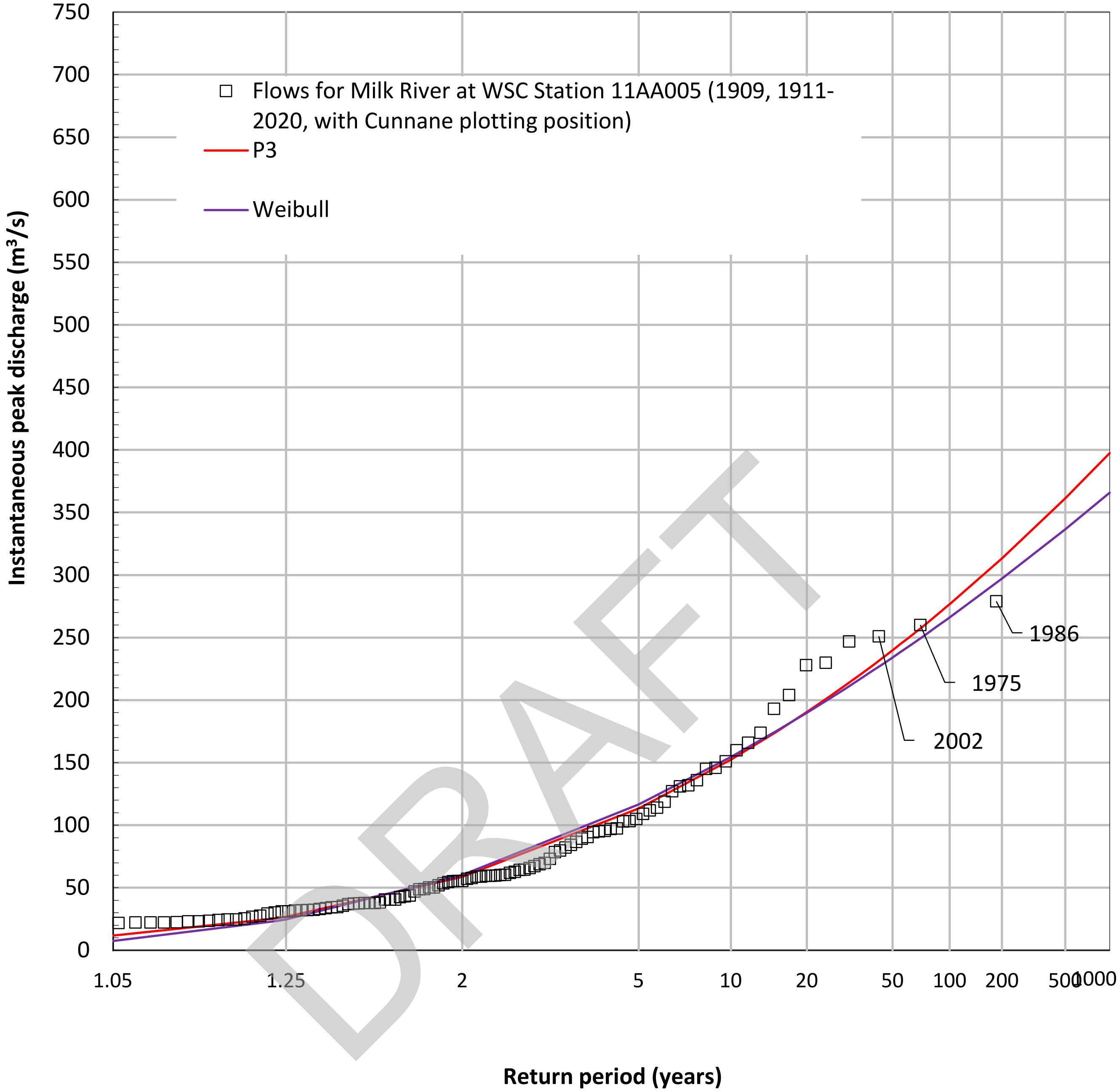

SCALE – AS SHOWN

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Units: As Shown

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MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

COMPARISON OF PEARSON III AND WEIBULL FLOOD FREQUENCY CURVES FOR MILK RIVER AT MILK RIVER

FIGURE 8

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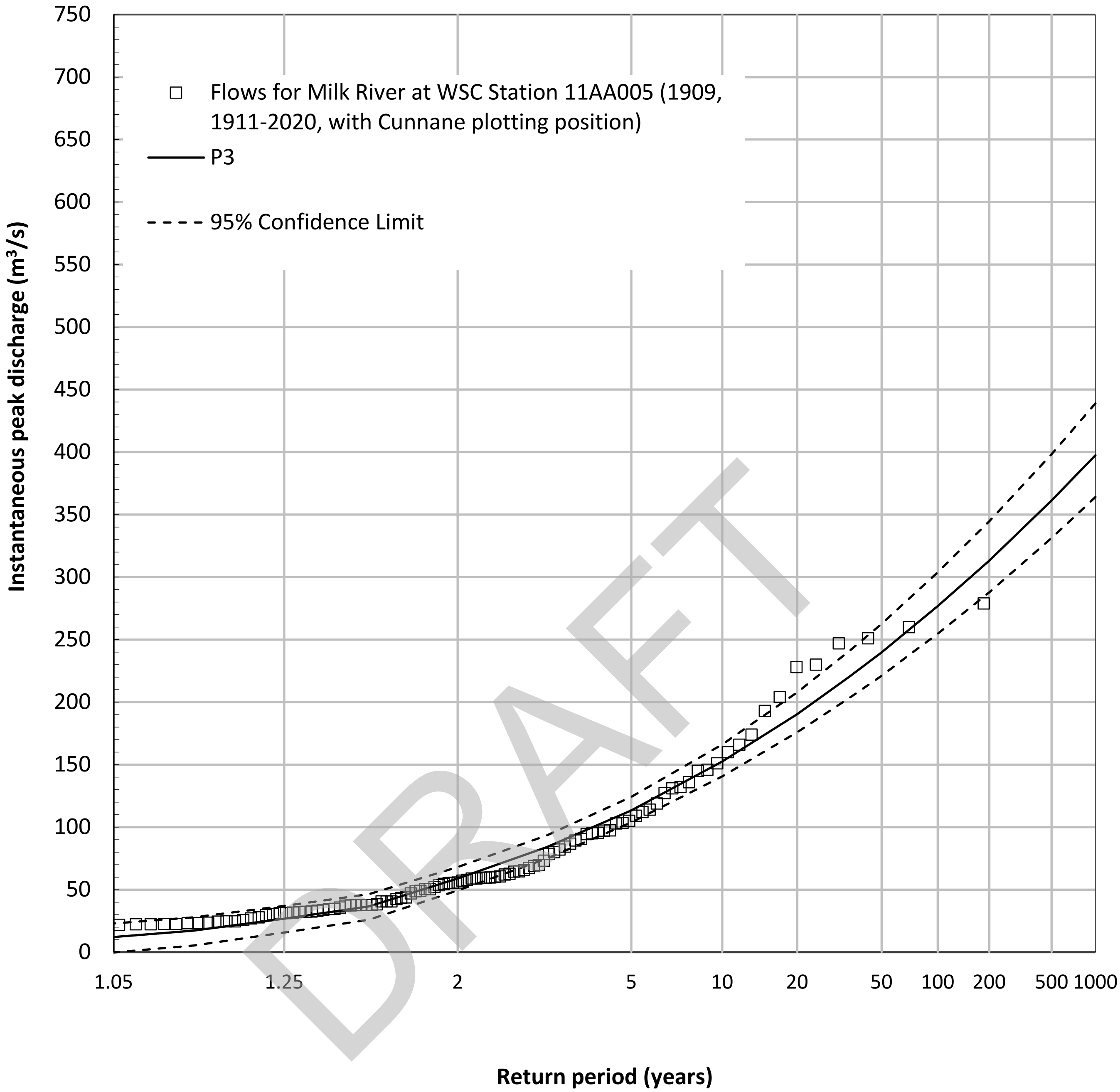

Alberta	SCALE – AS SHOWN	MILK RIVER FLOOD STUDY OPEN WATER HYDROLOGY ASSESSMENT PEARSON III FLOOD FREQUENCY CURVES FOR MILK RIVER AT MILK RIVER
nhc northwest hydraulic consultants	Coordinate System: Units: As Shown	
	Job: 1006666 / *Date: 30-AUG-2021*	*FIGURE 9*

Classification: Public

Appendix A

Additional Evaluated Frequency Distributions

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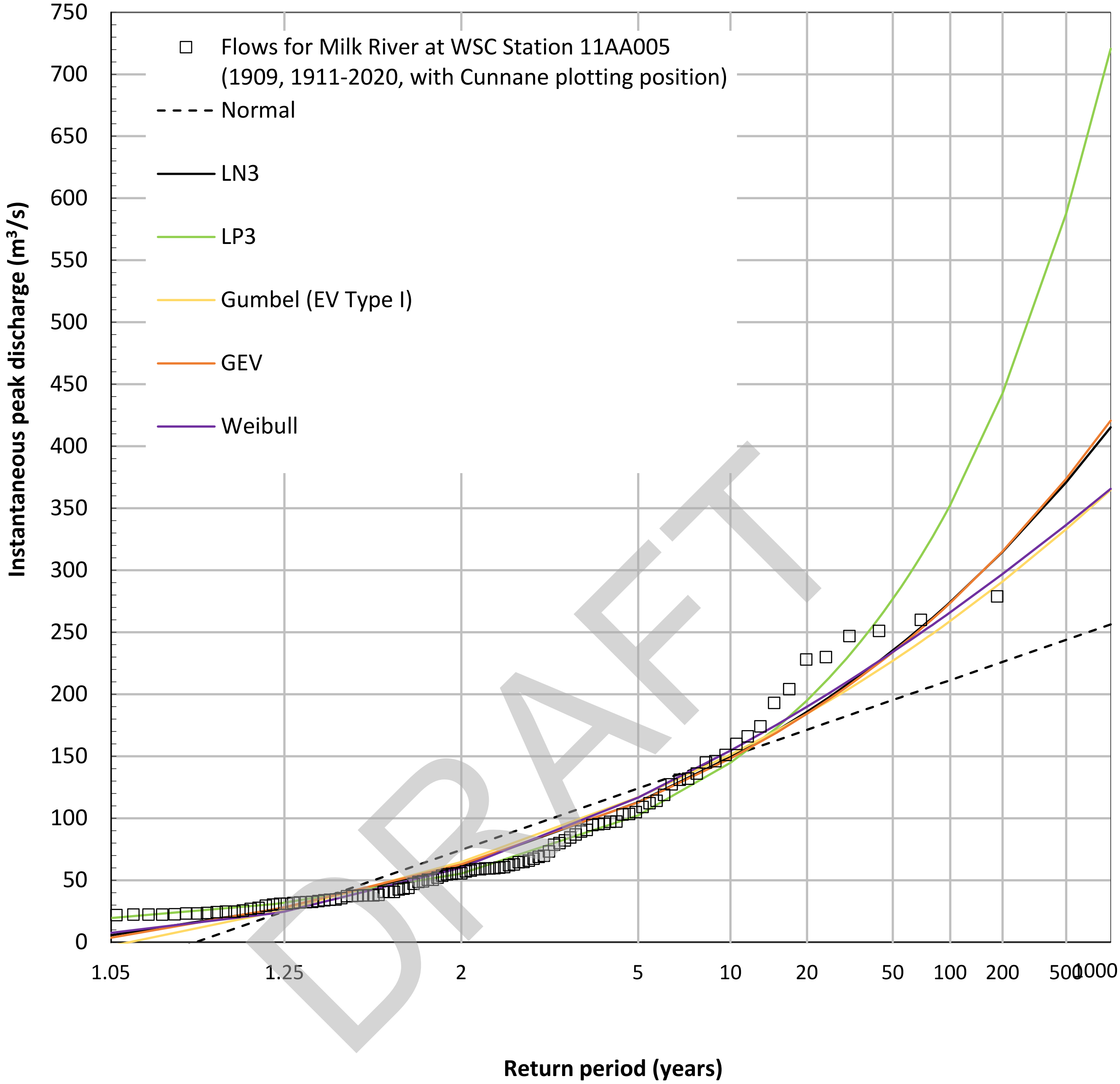

SCALE – AS SHOWN

Coordinate System:
Units: As Shown

Job: 1006666 | *Date: 08-JUL-2021*

MILK RIVER FLOOD STUDY
OPEN WATER HYDROLOGY ASSESSMENT

SINGLE STATION FLOOD FREQUENCY ANALYSIS

FIGURE A- 1

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APPENDIX D

SENSITIVITY ANALYSIS RESULTS

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Table D-1 Sensitivity analysis results for flood frequency estimates

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		Lower 95% Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	Upper 95% Limit of Flood Frequency Estimates
XS-56	8108.50	1043.54	1043.65	1043.76
XS-55	7888.90	1043.29	1043.39	1043.48
XS-54	7720.10	1043.15	1043.28	1043.38
XS-53	7476.10	1042.94	1043.06	1043.21
XS-52	7286.60	1042.86	1042.99	1043.13
XS-51	7077.30	1042.49	1042.64	1042.80
XS-50	6922.70	1042.26	1042.38	1042.50
XS-49	6716.20	1042.17	1042.30	1042.42
XS-48	6485.00	1041.90	1042.02	1042.17
XS-47	6310.80	1041.88	1042.01	1042.16
XS-46	6124.80	1041.80	1041.93	1042.09
XS-45	6007.10	1041.71	1041.84	1041.99
XS-44	5836.30	1041.51	1041.64	1041.80
XS-43	5744.30	1041.52	1041.65	1041.81
XS-42	5623.20	1041.43	1041.56	1041.72
XS-41	5465.10	1041.36	1041.49	1041.65
XS-40	5263.60	1041.12	1041.24	1041.40
XS-39	5154.70	1041.01	1041.16	1041.32
XS-38	5045.10	1040.99	1041.13	1041.29
XS-37	4995.40	1040.95	1041.08	1041.23
XS-36	4983.40	1040.88	1041.01	1041.17
XS-35	4948.90	1040.86	1040.99	1041.15
XS-34	4928.90	1040.84	1040.97	1041.12
XS-33	4909.50	1040.82	1040.96	1041.11
XS-32	4889.30	1040.76	1040.89	1041.04
XS-31	4848.70	1040.59	1040.71	1040.85
XS-30	4818.80	1040.58	1040.70	1040.83
XS-29	4798.50	1040.54	1040.65	1040.78
XS-28	4743.90	1040.49	1040.61	1040.75
XS-27	4599.80	1040.21	1040.35	1040.51
XS-26	4395.50	1040.05	1040.18	1040.33
XS-25	4232.40	1039.56	1039.68	1039.82
XS-24	4056.20	1039.36	1039.48	1039.61
XS-23	3823.20	1038.91	1039.02	1039.15
XS-22	3648.20	1038.76	1038.87	1038.99
XS-21	3435.30	1038.53	1038.64	1038.78

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Classification: Public

Table D-1 Sensitivity analysis results for flood frequency estimates (continued)

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Flood Frequency Estimates		
		Lower 95% Limit of Flood Frequency Estimates	Adopted Flood Frequency Estimates	Upper 95% Limit of Flood Frequency Estimates
XS-20	3241.50	1038.18	1038.27	1038.37
XS-19	2997.30	1037.73	1037.82	1037.93
XS-18	2821.60	1037.52	1037.61	1037.72
XS-17	2739.70	1037.45	1037.56	1037.68
XS-16	2625.90	1037.43	1037.54	1037.66
XS-15	2464.80	1037.15	1037.27	1037.42
XS-14	2316.20	1037.06	1037.18	1037.33
XS-13	2162.60	1036.77	1036.88	1037.02
XS-12	2031.60	1036.62	1036.74	1036.88
XS-11	1833.80	1036.46	1036.60	1036.76
XS-10	1625.00	1036.33	1036.47	1036.62
XS-09	1448.00	1036.21	1036.35	1036.51
XS-08	1215.50	1035.50	1035.62	1035.76
XS-07	989.40	1035.09	1035.20	1035.32
XS-06	819.00	1034.67	1034.78	1034.90
XS-05	580.30	1034.24	1034.36	1034.50
XS-04	443.00	1034.05	1034.17	1034.31
XS-03	216.60	1033.63	1033.74	1033.89
XS-02	104.90	1033.45	1033.57	1033.73
XS-01	0.00	1033.41	1033.53	1033.68
Average Difference		-0.12	0.00	0.14
Maximum Difference		-0.15	0.00	0.16

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Classification: Public

Table D-2 Sensitivity analysis results for downstream boundary conditions

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Condition		
		Low Normal Depth Slope (S = 0.0008 m/m)	Adopted Normal Depth Slope (S= 0.001 m/m)	High Normal Depth Slope (S = 0.0012 m/m)
XS-56	8108.50	1043.65	1043.65	1043.65
XS-55	7888.90	1043.39	1043.39	1043.39
XS-54	7720.10	1043.28	1043.28	1043.28
XS-53	7476.10	1043.06	1043.06	1043.06
XS-52	7286.60	1042.99	1042.99	1042.99
XS-51	7077.30	1042.64	1042.64	1042.64
XS-50	6922.70	1042.38	1042.38	1042.38
XS-49	6716.20	1042.30	1042.30	1042.30
XS-48	6485.00	1042.02	1042.02	1042.02
XS-47	6310.80	1042.01	1042.01	1042.01
XS-46	6124.80	1041.93	1041.93	1041.93
XS-45	6007.10	1041.84	1041.84	1041.84
XS-44	5836.30	1041.64	1041.64	1041.64
XS-43	5744.30	1041.65	1041.65	1041.65
XS-42	5623.20	1041.56	1041.56	1041.56
XS-41	5465.10	1041.49	1041.49	1041.49
XS-40	5263.60	1041.24	1041.24	1041.24
XS-39	5154.70	1041.16	1041.16	1041.16
XS-38	5045.10	1041.13	1041.13	1041.13
XS-37	4995.40	1041.08	1041.08	1041.08
XS-36	4983.40	1041.01	1041.01	1041.01
XS-35	4948.90	1040.99	1040.99	1040.99
XS-34	4928.90	1040.97	1040.97	1040.97
XS-33	4909.50	1040.96	1040.96	1040.96
XS-32	4889.30	1040.89	1040.89	1040.89
XS-31	4848.70	1040.71	1040.71	1040.71
XS-30	4818.80	1040.70	1040.70	1040.70
XS-29	4798.50	1040.65	1040.65	1040.65
XS-28	4743.90	1040.61	1040.61	1040.61
XS-27	4599.80	1040.35	1040.35	1040.35
XS-26	4395.50	1040.18	1040.18	1040.18
XS-25	4232.40	1039.68	1039.68	1039.68
XS-24	4056.20	1039.48	1039.48	1039.48
XS-23	3823.20	1039.02	1039.02	1039.02
XS-22	3648.20	1038.87	1038.87	1038.87
XS-21	3435.30	1038.64	1038.64	1038.64

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Classification: Public

Table D-2 Sensitivity analysis results for downstream boundary conditions (continued)

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Downstream Boundary Condition		
		Low Normal Depth Slope (S = 0.0008 m/m)	Adopted Normal Depth Slope (S= 0.001 m/m)	High Normal Depth Slope (S = 0.0012 m/m)
XS-20	3241.50	1038.27	1038.27	1038.27
XS-19	2997.30	1037.82	1037.82	1037.82
XS-18	2821.60	1037.61	1037.61	1037.61
XS-17	2739.70	1037.56	1037.56	1037.56
XS-16	2625.90	1037.54	1037.54	1037.54
XS-15	2464.80	1037.27	1037.27	1037.27
XS-14	2316.20	1037.18	1037.18	1037.18
XS-13	2162.60	1036.88	1036.88	1036.88
XS-12	2031.60	1036.74	1036.74	1036.74
XS-11	1833.80	1036.60	1036.60	1036.60
XS-10	1625.00	1036.47	1036.47	1036.47
XS-09	1448.00	1036.35	1036.35	1036.35
XS-08	1215.50	1035.62	1035.62	1035.62
XS-07	989.40	1035.20	1035.20	1035.20
XS-06	819.00	1034.79	1034.78	1034.77
XS-05	580.30	1034.40	1034.36	1034.34
XS-04	443.00	1034.23	1034.17	1034.14
XS-03	216.60	1033.87	1033.74	1033.67
XS-02	104.90	1033.75	1033.57	1033.45
XS-01	0.00	1033.71	1033.53	1033.40
Average Difference		0.01	0.00	-0.01
Maximum Difference		0.18	0.00	-0.13

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Classification: Public

Table D-3 Sensitivity analysis results for channel roughness

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
XS-56	8108.50	1043.46	1043.65	1043.78
XS-55	7888.90	1043.23	1043.39	1043.51
XS-54	7720.10	1043.10	1043.28	1043.38
XS-53	7476.10	1042.89	1043.06	1043.21
XS-52	7286.60	1042.84	1042.99	1043.12
XS-51	7077.30	1042.37	1042.64	1042.84
XS-50	6922.70	1042.18	1042.38	1042.55
XS-49	6716.20	1042.13	1042.30	1042.43
XS-48	6485.00	1041.84	1042.02	1042.18
XS-47	6310.80	1041.85	1042.01	1042.15
XS-46	6124.80	1041.78	1041.93	1042.08
XS-45	6007.10	1041.70	1041.84	1041.98
XS-44	5836.30	1041.47	1041.64	1041.80
XS-43	5744.30	1041.51	1041.65	1041.79
XS-42	5623.20	1041.40	1041.56	1041.72
XS-41	5465.10	1041.35	1041.49	1041.64
XS-40	5263.60	1041.07	1041.24	1041.40
XS-39	5154.70	1040.96	1041.16	1041.32
XS-38	5045.10	1040.97	1041.13	1041.27
XS-37	4995.40	1040.94	1041.08	1041.22
XS-36	4983.40	1040.87	1041.01	1041.15
XS-35	4948.90	1040.85	1040.99	1041.13
XS-34	4928.90	1040.83	1040.97	1041.10
XS-33	4909.50	1040.82	1040.96	1041.09
XS-32	4889.30	1040.74	1040.89	1041.03
XS-31	4848.70	1040.54	1040.71	1040.86
XS-30	4818.80	1040.54	1040.70	1040.84
XS-29	4798.50	1040.49	1040.65	1040.80
XS-28	4743.90	1040.45	1040.61	1040.76
XS-27	4599.80	1040.12	1040.35	1040.54
XS-26	4395.50	1040.02	1040.18	1040.33
XS-25	4232.40	1039.42	1039.68	1039.91
XS-24	4056.20	1039.27	1039.48	1039.65
XS-23	3823.20	1038.79	1039.02	1039.22
XS-22	3648.20	1038.69	1038.87	1039.02
XS-21	3435.30	1038.46	1038.64	1038.80

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Classification: Public

Table D-3 Sensitivity analysis results for channel roughness (continued)

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Channel Roughness		
		Low Channel Roughness (-15%)	Adopted Roughness	High Channel Roughness (+15%)
XS-20	3241.50	1038.12	1038.27	1038.42
XS-19	2997.30	1037.64	1037.82	1037.97
XS-18	2821.60	1037.47	1037.61	1037.73
XS-17	2739.70	1037.40	1037.56	1037.68
XS-16	2625.90	1037.40	1037.54	1037.65
XS-15	2464.80	1037.07	1037.27	1037.45
XS-14	2316.20	1037.01	1037.18	1037.34
XS-13	2162.60	1036.70	1036.88	1037.05
XS-12	2031.60	1036.57	1036.74	1036.89
XS-11	1833.80	1036.44	1036.60	1036.75
XS-10	1625.00	1036.34	1036.47	1036.60
XS-09	1448.00	1036.22	1036.35	1036.48
XS-08	1215.50	1035.33	1035.62	1035.86
XS-07	989.40	1035.00	1035.20	1035.38
XS-06	819.00	1034.56	1034.78	1034.96
XS-05	580.30	1034.13	1034.36	1034.56
XS-04	443.00	1033.95	1034.17	1034.37
XS-03	216.60	1033.54	1033.74	1033.96
XS-02	104.90	1033.31	1033.57	1033.82
XS-01	0.00	1033.31	1033.53	1033.74
Average Difference		-0.18	0.00	0.16
Maximum Difference		-0.29	0.00	0.25

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Classification: Public

Table D-4 Sensitivity analysis results for overbank roughness

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
XS-56	8108.50	1043.62	1043.65	1043.68
XS-55	7888.90	1043.36	1043.39	1043.42
XS-54	7720.10	1043.24	1043.28	1043.31
XS-53	7476.10	1043.03	1043.06	1043.08
XS-52	7286.60	1042.95	1042.99	1043.01
XS-51	7077.30	1042.62	1042.64	1042.65
XS-50	6922.70	1042.34	1042.38	1042.41
XS-49	6716.20	1042.25	1042.30	1042.33
XS-48	6485.00	1041.97	1042.02	1042.06
XS-47	6310.80	1041.96	1042.01	1042.05
XS-46	6124.80	1041.88	1041.93	1041.97
XS-45	6007.10	1041.79	1041.84	1041.88
XS-44	5836.30	1041.60	1041.64	1041.67
XS-43	5744.30	1041.60	1041.65	1041.69
XS-42	5623.20	1041.53	1041.56	1041.59
XS-41	5465.10	1041.46	1041.49	1041.52
XS-40	5263.60	1041.22	1041.24	1041.26
XS-39	5154.70	1041.15	1041.16	1041.16
XS-38	5045.10	1041.11	1041.13	1041.14
XS-37	4995.40	1041.06	1041.08	1041.10
XS-36	4983.40	1040.99	1041.01	1041.03
XS-35	4948.90	1040.97	1040.99	1041.01
XS-34	4928.90	1040.95	1040.97	1040.99
XS-33	4909.50	1040.93	1040.96	1040.97
XS-32	4889.30	1040.87	1040.89	1040.91
XS-31	4848.70	1040.68	1040.71	1040.73
XS-30	4818.80	1040.68	1040.70	1040.72
XS-29	4798.50	1040.63	1040.65	1040.67
XS-28	4743.90	1040.59	1040.61	1040.63
XS-27	4599.80	1040.34	1040.35	1040.35
XS-26	4395.50	1040.16	1040.18	1040.19
XS-25	4232.40	1039.68	1039.68	1039.69
XS-24	4056.20	1039.46	1039.48	1039.49
XS-23	3823.20	1039.01	1039.02	1039.03
XS-22	3648.20	1038.85	1038.87	1038.88
XS-21	3435.30	1038.64	1038.64	1038.65

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Classification: Public

Table D-4 Sensitivity analysis results for overbank roughness (continued)

Cross Section	River Station (m)	100-Year Flood Levels (m) for Varying Overbank Roughness		
		Low Overbank Roughness (-20%)	Adopted Roughness	High Overbank Roughness (+20%)
XS-20	3241.50	1038.25	1038.27	1038.29
XS-19	2997.30	1037.79	1037.82	1037.84
XS-18	2821.60	1037.57	1037.61	1037.64
XS-17	2739.70	1037.53	1037.56	1037.57
XS-16	2625.90	1037.51	1037.54	1037.56
XS-15	2464.80	1037.25	1037.27	1037.28
XS-14	2316.20	1037.16	1037.18	1037.20
XS-13	2162.60	1036.85	1036.88	1036.91
XS-12	2031.60	1036.70	1036.74	1036.77
XS-11	1833.80	1036.57	1036.60	1036.62
XS-10	1625.00	1036.44	1036.47	1036.49
XS-09	1448.00	1036.33	1036.35	1036.37
XS-08	1215.50	1035.63	1035.62	1035.62
XS-07	989.40	1035.19	1035.20	1035.20
XS-06	819.00	1034.75	1034.78	1034.79
XS-05	580.30	1034.35	1034.36	1034.37
XS-04	443.00	1034.16	1034.17	1034.17
XS-03	216.60	1033.72	1033.74	1033.76
XS-02	104.90	1033.56	1033.57	1033.58
XS-01	0.00	1033.51	1033.53	1033.54
Average Difference		-0.03	0.00	0.02
Maximum Difference		-0.05	0.00	0.04

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Classification: Public

APPENDIX E

OPEN WATER FLOOD INUNDATION MAP LIBRARY

(provided under separate cover)

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APPENDIX F

FLOODWAY CRITERIA MAP

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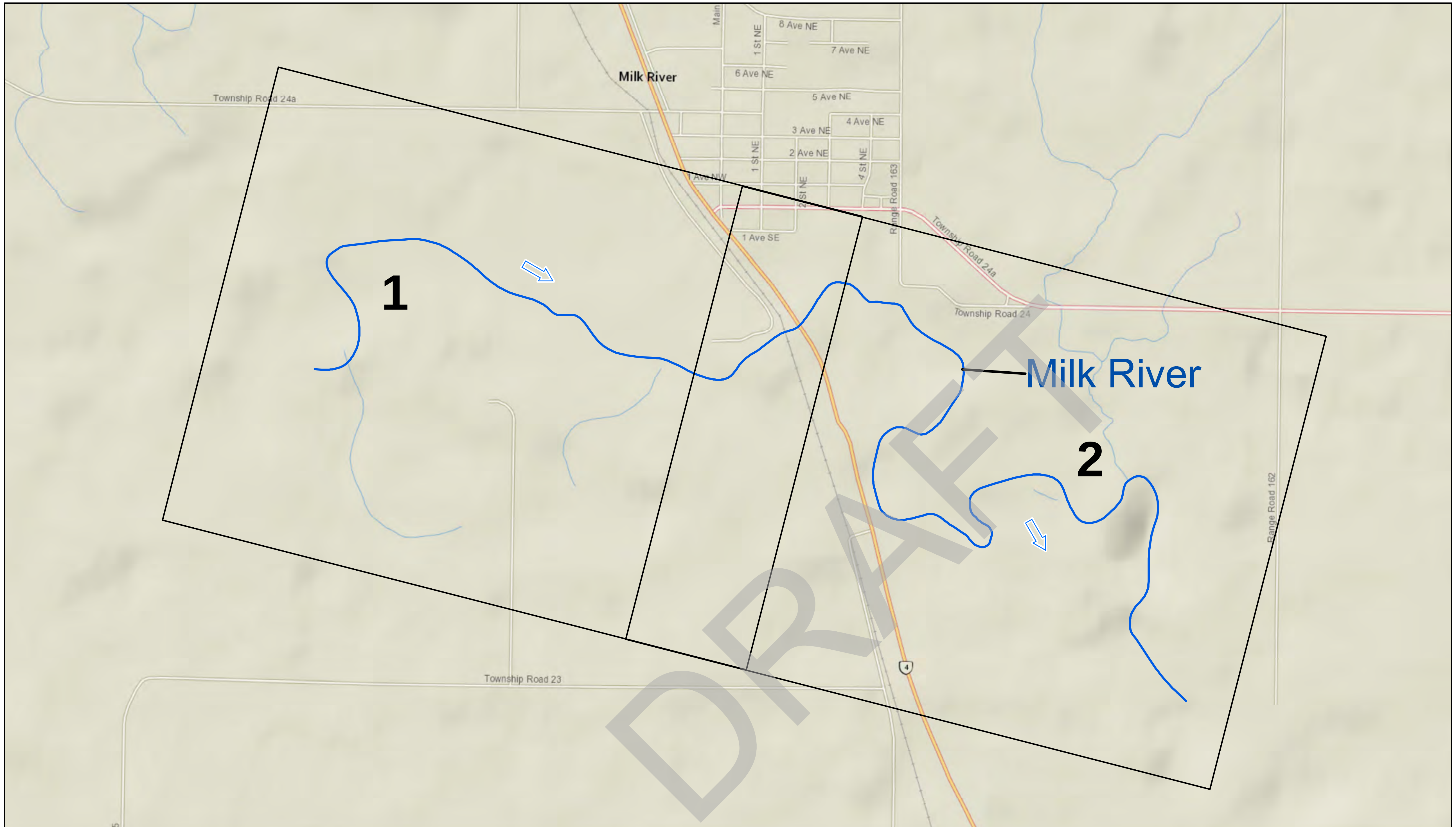


Notes to Users:

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

Definitions:

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

Definitions (continued):

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

Data Sources and References:

1. Orthophoto imagery acquired by OGL Engineering for Alberta Environment and Parks: *OGL Engineering (2021). Milk River aerial imagery acquisition memorandum, project number 2021-500, submitted to Alberta Environment and Parks, 5 pp.*
2. Base data from Natural Resources Canada, Alberta Environment and Parks, and Altalis.
3. Additional base mapping from Esri.

Alberta

nhc
northwest hydraulic consultants

FLOW DIRECTION
STUDY REACH
MAP SHEET

SCALE - 1:18,000
0 300 600 M
N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	DJH

Job: 1006666 | Date: 11-MAR-2022

MILK RIVER FLOOD STUDY

FLOODWAY CRITERIA MAP

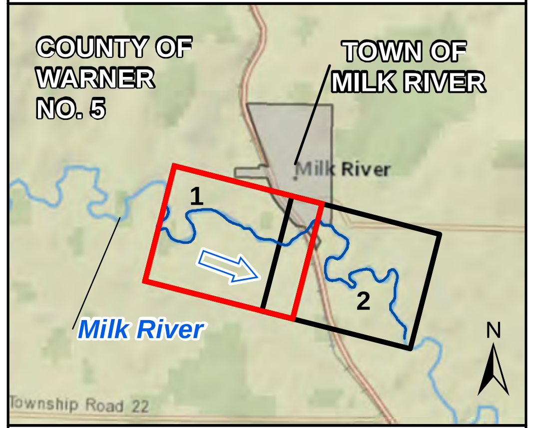
INDEX MAP

Classification: Public

JY_P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_JY_Map_IndexMap_FloodwayCriteria.mxd

Alberta

nhc northwest hydraulic consultants



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

SCALE - 1:7,500

0 100 200 M

N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	DJH
Job: 1006666	Date: 23-MAR-2022	

MILK RIVER FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 1 OF 2

JY_P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_JY_Map_FloodwayCriteria.mxd

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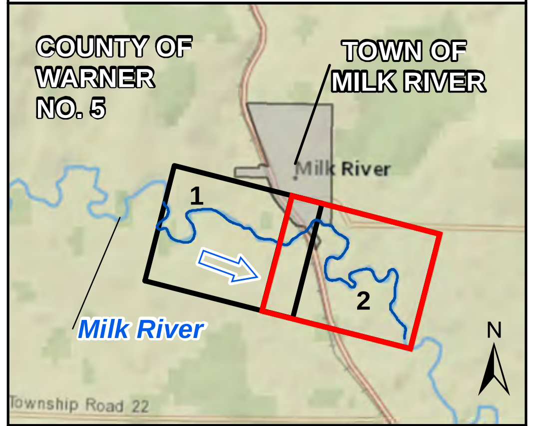


FLOW DIRECTION
BRIDGE
MODEL CROSS SECTION
LOCAL ROAD
PROVINCIAL HIGHWAY
RAILWAY
STUDY LIMIT
BANK STATION
PROPOSED FLOODWAY LIMIT
VELOCITY ≥ 1 m/s
PROPOSED FLOODWAY BOUNDARY
1m DEPTH CONTOUR
DEPTH ≥ 1 m
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
TOWN OF MILK RIVER

SCALE - 1:7,500
0 100 200 M
N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer MMM	*GIS* JY	*Reviewer* DJH
Job: 1006666	*Date: 23-MAR-2022*	

MILK RIVER FLOOD STUDY

FLOODWAY CRITERIA MAP

SHEET 2 OF 2

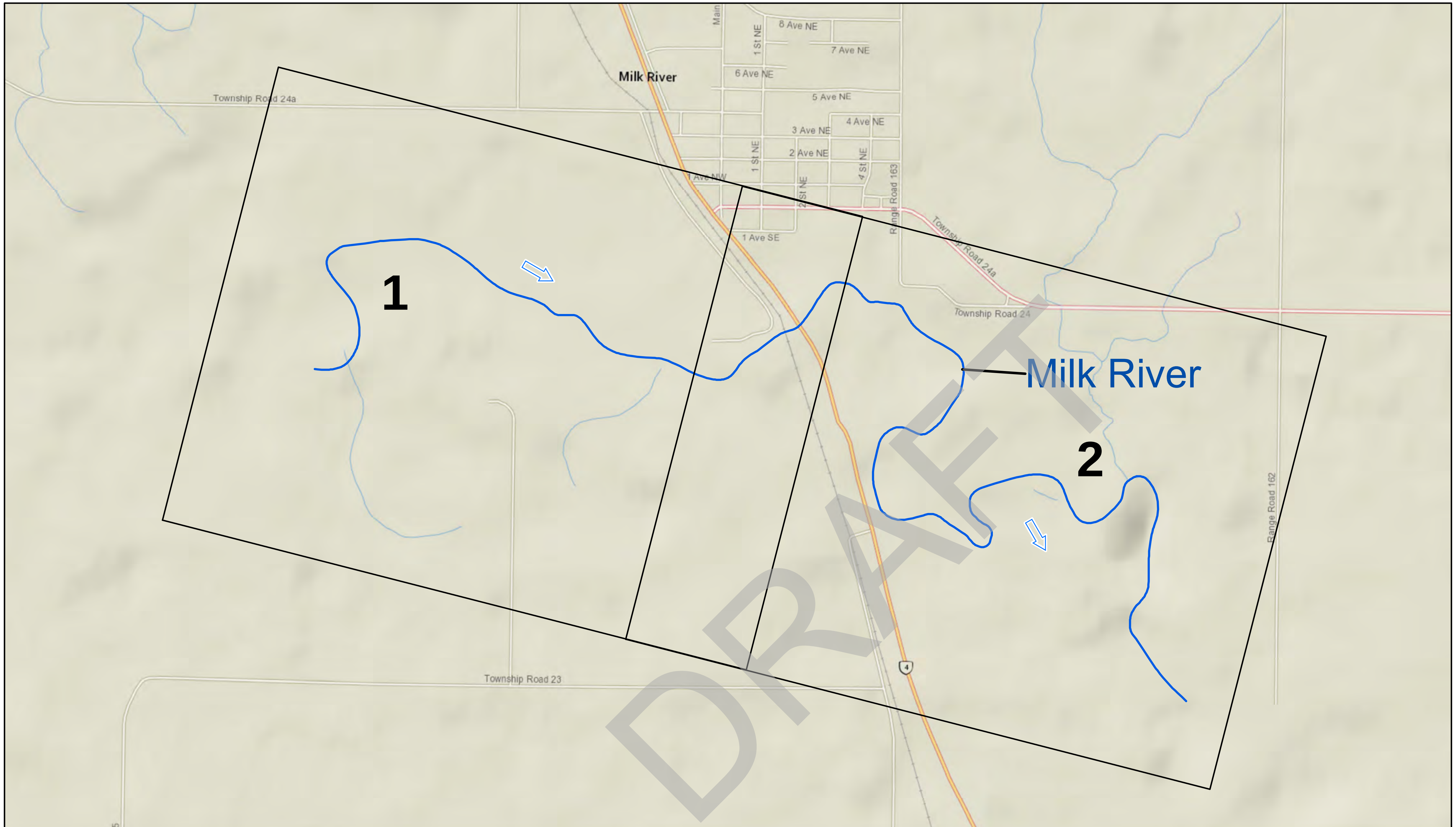
JY P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_JY_Map_FloodwayCriteria.mxd

Classification: Public

APPENDIX G

FLOOD HAZARD MAP

DRAFT



Alberta

nhc
northwest hydraulic consultants

FLOW DIRECTION
STUDY REACH
MAP SHEET

SCALE - 1:18,000
0 300 600 M
N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer MMM	*GIS* JY	*Reviewer* DJH

Job: 1006666 Date: 11-MAR-2022

MILK RIVER FLOOD STUDY

DESIGN FLOOD HAZARD MAP

INDEX MAP

Notes to Users:

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

Definitions:

Flood Hazard Map - A flood hazard map is a specific type of flood map that identifies the area flooded for the 1:100 design flood, and divides that flood hazard area into floodway and flood fringe zones. Flood hazard maps can also show additional flood hazard information, including the incremental areas at risk for more severe floods like the 1:200 and 1:500 floods. Flood hazard maps are typically used for long-term flood hazard area management and land-use planning.
Design Flood - The design flood standard in Alberta is the 1:100 flood, which is a flood that has a 1% chance of being equaled or exceeded in any given year. The design flood is typically based on the 1:100 open water flood, but it can also reflect 1:100 ice jam flood levels or be based on a historical flood event. Different sized floods have different chances of occurring – for example, a 1:200 flood has a 0.5% chance of occurring in any given year and a 1:500 flood has a 0.2% chance of occurring in any given year – but only the 1:100 design flood is used to define the floodway and flood fringe zones on flood hazard maps.
Floodway - When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 1:100 design flood. When a flood hazard map is updated, the floodway will not get larger in most circumstances to maintain long-term regulatory certainty, even if the flood hazard area gets larger or design flood levels get higher.
Flood Fringe - The flood fringe is the area outside of the floodway that is flooded or could be flooded during the 1:100 design flood. The flood fringe typically represents areas with shallower, slower, and less destructive flooding, but it may also include "high hazard flood fringe" areas. Areas at risk of flooding behind flood berms may also be mapped as "protected flood fringe" areas.
High Hazard Flood Fringe - The high hazard flood fringe identifies areas within the flood fringe with deeper or faster moving water than the rest of the flood fringe. High hazard flood fringe areas are likely to be most significant for flood maps that are being updated, but they may also be included in new flood maps.
Protected Flood Fringe - The protected flood fringe identifies areas that could be flooded if dedicated flood berms fail or do not work as designed during the 1:100 design flood, even if they are not overtopped. Protected flood fringe areas are part of the flood fringe and do not differentiate between areas with deeper or faster moving water and shallower or slower moving water.

Data Sources and References:

1. Orthophoto imagery acquired by OGL Engineering for Alberta Environment and Parks: *OGL Engineering (2021). Milk River aerial imagery acquisition memorandum, project number 2021-500, submitted to Alberta Environment and Parks, 5 pp.*
2. Base data from Natural Resources Canada, Alberta Environment and Parks, and Altalis.
3. Additional base mapping from Esri.

Classification: Public

J:\P_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_JY_Map_IndexMap_FloodHazard.mxd

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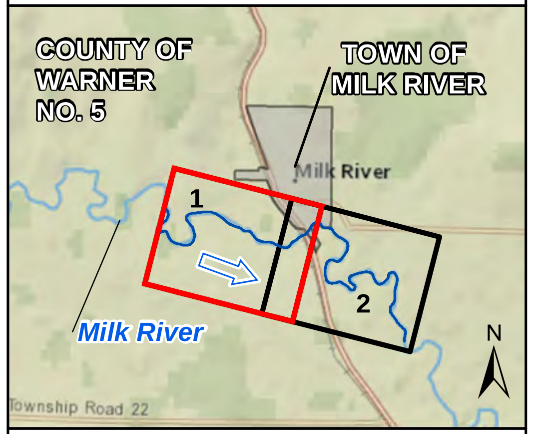

FLOW DIRECTION
BRIDGE
MODEL CROSS SECTION
LOCAL ROAD
PROVINCIAL HIGHWAY
RAILWAY
TOWN OF MILK RIVER
STUDY LIMIT
GOVERNING FLOODWAY
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

SCALE - 1:7,500
0 100 200 M
N

Coordinate System: NAD 1983 CSRS 3TM 111;
Vertical Datum: CGVD28 HTv2.0; Units: Metres

Engineer	GIS	Reviewer
MMM	JY	DJH
Job: 1006666	Date: 23-MAR-2022	

MILK RIVER FLOOD STUDY

DESIGN FLOOD HAZARD MAP

SHEET 1 OF 2

JY_P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_JY_Map_FloodHazard.mxd

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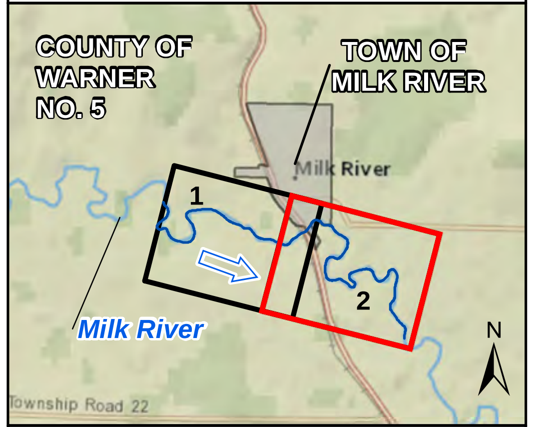

- FLOW DIRECTION
- BRIDGE
- MODEL CROSS SECTION
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SCALE - 1:7,500
0 100 200 M
N

Coordinate System: NAD 1983 CSRS 3TM 111; Vertical Datum: CGVD28 HTv2.0; Units: Metres

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MILK RIVER FLOOD STUDY

DESIGN FLOOD HAZARD MAP

SHEET 2 OF 2

JY: P:_Projects (Active)\1006666 Milk River Flood Study\90 GIS\1006666_JY_Map_FloodHazard.mxd

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