HYDROTECHNICAL DESIGN REPORT

JEAN MARIE RIVER BRIDGE REPLACEMENT

HIGHWAY 1 (MACKENZIE HIGHWAY)

Integrated Services | Innovative Solutions

Prepared for: JACOBS AND THE GOVERNMENT OF NORTHWEST TERRITORIES
APRIL 2024

Matrix Solutions Inc.
A Montrose Environmental Company

www.matrix-solutions.com

HYDROTECHNICAL DESIGN REPORT

JEAN MARIE RIVER BRIDGE REPLACEMENT

HIGHWAY 1 (MACKENZIE HIGHWAY)

Prepared for Jacobs and the Government of Northwest Territories, April 2024

Thomas Schaepsmeyer, M.Eng., P.Eng.
Hydrotechnical Engineer
(Registered in British Columbia)

REGISTERED PROFESSIONAL ENGINEER
N.M. KRYGSMAN
LICENSEE
2024-04-02
NT/NU

reviewed by
Nicholas Krygsman, P.Eng. (L5001)
Principal, Practice Lead - Engineering

reviewed by
Katy Curtis, P.Eng.
Principal Hydrotechnical Engineer
(Registered in Yukon, British Columbia, Alberta, Newfoundland and Labrador)

PERMIT TO PRACTICE
MATRIX SOLUTIONS INC.
Signature
Date 2024-04-02
PERMIT NUMBER: P 378
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

CONTRIBUTORS

Name	Job Title	Role
Nicholas Krygsman, P.Eng.	Principal, Practice Lead – Engineering	Engineer of Record
Thomas Schaepsmeyer, M.Eng., P.Eng.	Hydrotechnical Engineer	Final report author
David Kushner, P.Eng.	Hydrotechnical Engineer	Draft report author
Katy Curtis, P.Eng.	Principal, Hydrotechnical Engineer	Engineering technical review
Wim Veldman, M.Sc., FEIC, P.Eng.	Wim M Veldman Consulting	Senior Hydrotechnical Advisor
Ziyang Zhang, M.Sc., P.Eng.	Water Resources Engineer	Hydrologic analysis and hydraulic modelling
Zavier Berti, M.Sc., E.I.T.	Water Resources Engineer-in-Training	Riprap and scour calculations

VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V0.1	17-Apr-2023	Draft	35370-522 JMB Hydrotech R 2023-04-17 draft V0.1.docx	Issued to client for review
V1.0	21-Jul-2023	Final	35370-522 JMB Hydrotech R 2023-07-21 Final V1.0.docx	Issued to client as final
V2.0	13-Dec-2023	Final Revised	35370-522 JMB Hydrotech R 2023-12-13 Final V2.0.docx	Revised following site visit Issued to client as final
V3.0	12-Jan-2024	Final Revised	35370-522 JMB Hydrotech R 2024-01-12 Final V3.0.docx	Revised following client feedback Issued to client as final
V4.0	02-Apr-2024	Final Revised	35370-522 JMB Hydrotech R 2024-03-28 Final V3.0.docx	Revised following feedback from GNWT Issued to client as final

TABLE OF CONTENTS

IN-TEXT TABLES

FIGURES

APPENDIX

1 INTRODUCTION

Matrix Solutions Inc. prepared this hydrotechnical design report for the Mackenzie Highway (Highway 1) bridge replacement project over the Jean Marie River. The bridge is approximately 65 km south of Fort Simpson as measured along Highway 1, and immediately south of the junction with Highway 7 as shown on Figure 1.

Matrix provides this report to the Government of the Northwest Territories (GNWT) and Jacobs. GNWT is the bridge owner. Jacobs is the overall bridge designers and prime consultant for the project.

This report has undergone the following key updates.

- The hydrotechnical draft report was issued by Matrix on April 17, 2023, and considered a single-span and three-span option for the bridge. Subsequently, the GNWT and Jacobs decided that only the single-span bridge option would be progressed. Information and discussion on the three-span option has been kept in these subsequent report revisions for completeness and in-case the three-span option is reconsidered in the future.

- Matrix completed a site reconnaissance on September 27 and 28, 2023, and subsequently updated this report and hydrotechnical recommendations. Key updates include current photos, and observations and measurements of the existing riprap and riverbed substrate at the bridge. We confirmed that the existing riprap is stable/competent and can be repurposed for the new bridge. The riverbed substrate at the bridge is rocky with cobbles that are >200 mm in diameter, based on this we predict that the design channel scour depth is at the present thalweg elevation (i.e., a launching riprap apron or toe trench is not required to protect the riprap from undermining).

- Jacobs and Matrix simplified the riprap armouring to prevent work within the wetted perimeter of the river.

1.1 Existing Bridge and Proposed Bridge Options

The bridge location is shown on Figures 1 and 3. The new bridge will be at the same alignment as the existing bridge.

The existing bridge, constructed in 1969, is a single-span bridge with a clear span length of 35 m between the vertical abutments. The abutments are on timber piles with compacted gravels underneath (GNWT 2022a). There is riprap in front of the bridge abutments and riprap along the river bank approximately 8 m upstream and downstream of the bridge (Figure 2, Photograph 3). This riprap is rounded and equivalent to Class 2 riprap. The bridge has a flat grade with a low chord elevation of 205.54 m. The existing bridge does not meet the Canadian Highway Bridge Design Code (CHBDC) CL625 and CL800 loads and GNWT has decided to replace rather than rehabilitate the existing bridge.

Two different span options were considered for the proposed bridge:

- A single-span bridge with a clear span length of 37.4 m.

- A three-span bridge, with two 0.6 m wide circular instream piers, and a total span length of 42 m (a 20 m span between the piers, and 11 m spans between the piers and abutments). Two different girder options were considered for the three-span bridge but are the same from a hydrotechnical perspective because they have the same pier locations, pier diameters, and low chord elevation and thus are not differentiated in this report.

The proposed bridge by Jacobs has a minimum low chord elevation of 206.3 m on the south (right) bank versus a 1:100-year design water level of 205.1 m. The bridge and highway will be on a 1.25% grade across the river, with the higher elevation at the north bank.

A temporary bridge is proposed by Jacobs to allow traffic to cross the river during construction. Hydrotechnical recommendations for the temporary bridge are provided in a memorandum in Appendix A.

1.2 Scope of Report

This report provides details of the hydrotechnical assessment and the recommended hydrotechnical design parameters for the highway bridge including:

- the 1:100-year design flood and water level
- the design river ice level and forces
- the recommended minimum bridge low-chord elevation relative to the 1:100-year design water level, including consideration for climate change and clearances of ice, debris, and for navigation
- the recommendations for scour and erosion protection

2 DESIGN BASIS

2.1 Project Requirements

This report is based on the following hydrotechnical design requirements, standards, and guidelines, as per the project request for proposals (GNWT 2022a):

- GNWT project specific design criteria (GNWT 2022b).

    - The required design flood for the proposed bridge is the maximum instantaneous 1:100-year flood event.

- GNWT project specific freeboard[1].
    - The bridge must provide a minimum freeboard of 1.2 m above the 1:100-year flood (i.e., the minimum required freeboard is revised from 1.5 m (GNWT 2022b) to 1.2 m, per the design exception from GNWT dated April 20, 2023; GNWT 2023).
- *Canadian Highway Bridge Design Code S6-19* (CHBDC; CSA 2019).
- Transport Association of Canada (TAC) *Guide to Bridge Hydraulics* (TAC 2001).
- Alberta Transportation (AT) *Bridge Conceptual Design Guidelines* (AT 2020a).
    - AT guidelines account for climate change by including it, along with other uncertainties, within the site-specific freeboard. This is the approach taken herein.
- AT *Design Bulletin #45/2007 Use of Retaining Wall Structures for Bridges and Roadways in Active Watercourse Environments* (AT 2007)
    - Retaining walls are not proposed by Jacobs therefore this Bulletin is not referenced.
- AT *Best Practice Guideline #7 Spread Footings* (AT 2003a)
    - Spread footings are not proposed by Jacobs therefore this guideline is not referenced.

2.2 Design Guidelines

The following design standards and guidelines were also considered:

- British Columbia Ministry of Environment, Lands and Parks (B.C. MELP) *Riprap Design and Construction Guide* (B.C. MELP 2000).
- Engineers and Geoscientists of British Columbia (EGBC) *Natural Hazards: Legislated Flood Assessments in a Changing Climate in BC* (EGBC 2018).
    - EGBC recommends the potential effects of climate change are assessed using historical data and considering future projections for runoff and precipitation where available and appropriate for the site. Considering only historical data, EGBC recommends a climate change factor of 10% to 20%, with 10% justifiable if there are no historical trends.

[1] Freeboard – The clearance from the minimum soffit elevation to the design water level.

2.3 Available Information

The following key information was used for the hydrotechnical assessment:

1. Conceptual drawings of the single-span and three-span bridge options provided by Jacobs on March 24, 2023 and 50% design drawings of the single-span bridge option provided by Jacobs on June 19, 2023.

2. Photographs and observations from a site visit by some members of the design team on December 13, 2022, and photographs and observations by Katy Curtis, P.Eng. (Matrix) on September 27 and 28, 2023. Select photographs from the Matrix site visit are presented on Figure 2.

3. Hydrometric data from the Water Survey of Canada (WSC) gauge Jean Marie River at Highway 1 (10FB005), located on Jean Marie River about 40 m upstream of the bridge:

    - Discharge (flow) and water level data:

        - 47 years of daily flow data from April 1972 to 2019 (excluding 1980 due to large amounts of missing data).

        - 47 years of annual maximum daily flow data reported by WSC for 1973 to 2017 (excluding 1980 due to large amounts of missing data) and calculated by Matrix for 1972, 2018, and 2019.

        - 35 years of reported annual maximum instantaneous flow data from 1982 to 2017 (missing data in 2007).

        - 18 years of daily average water level data from 2002 to 2019.

        - Note: Water level elevation is computed by adding 199.624 m to the water level data, as provided by WSC (CGVD28 elevation datum). Elevation is converted from CGVD28 to CGVD2013 elevation datum by subtracting 0.54 m.

    - Notes and manual measurements by WSC staff:

        - Discharge and water level from 1973 to 2022, including winter measurements from 1996 to 2022 (an average of about seven measurements per year over the 50-year period).

        - Four discrete ice thickness measurements along with discharge and water level (December 2016, April 2018, December 2018, and December 2019).

    - The open water rating curve (water level vs. discharge) determined by WSC at the gauge.

- WSC has used 12 different open water rating curves between 1996 and present with minor shifts in the rating curve over time.

- The flood of record occurred on July 3 and 4, 1988, with a maximum instantaneous discharge of 216 m^3/s. WSC provided a measured water level of 6.02 m near the peak of the flood when the instantaneous discharge was 211 m^3/s (i.e., a water level elevation of 205.64 m CGVD28/ 205.10 m CGVD2013).

4. Weather data from the Environment Canada weather station at Fort Simpson (Climate ID 2202103); a 58-year record from 1963 to 2021.

5. Previous hydrotechnical report for the conceptual bridge design (Stantec 2019). The report included:

   - Estimation of the 1:100-year flood. A value of 258 m^3/s was computed with a flood frequency analysis using only the peak flow data (35 years) and the most conservative fitted frequency distribution (log normal with maximum likelihood fitting method).

   - Development of a 1D HEC-RAS hydraulic model of the existing bridge and proposed bridge options. The model was calibrated to the flood of record at the WSC gauge. Elevations for water levels and the conceptual bridge design were in the CGVD2013 elevation datum.

   - Site photographs from June 2017 and October 2019.

   - Some erosion observed in photographs from 1992 of the fill adjacent to the bridge abutments; the photographs were not included in Stantec's report.

6. Survey data of the river banks, river bed (bathymetry), and existing bridge completed by Stantec from October 10 to 12, 2019. Stantec completed the survey in CGVD2013 elevation datum.

7. Topographic elevation data from Natural Resources Canada (NRCAN) used to estimate the top of valley, outside the survey extents, for several sections within Matrix's hydraulic model. NRCAN data was released in 2021, 2 years after Stantec completed their report.

8. Aerial photography, obtained from the national air photo library, from 1947 to 1994, and satellite photography from 2022.

9. Drawings of the existing bridge including issued for construction drawings (1968), and rehabilitation drawings (1993 and 2004).

3 GENERAL RIVER AND SITE CONDITIONS

The Jean Marie River is in the boreal plains of the Deh Cho region of the Northwest Territories. The Deh Cho region is composed of two distinct physiographic areas – the high mountain cordillera to the west and the low interior plains to the east. The low plains are occupied by hundreds of lakes of various sizes. The entire region is underlain by discontinuous permafrost (Faria 2002).

The headwaters of Jean Marie River begin at 510 m elevation, about 100 km upstream of the bridge. The river collects several tributaries and flows through numerous small lakes and two larger lakes: Deep Lake and McGill Lake, located 35 km and 22 km upstream of the bridge, respectively. The drainage area at the bridge is 1,310 km^2 (Figure 1). The river joins with the Mackenzie River at 130 m elevation, approximately 60 km downstream of the bridge. The river is moderately sinuous between McGill Lake and the bridge, with straight reaches and occasional meanders. Downstream of the bridge and to its confluence with the Mackenzie River, the river is highly sinuous with frequent oxbow lakes and scars.

At the bridge location, the river is nearly straight with only a slight bend (the north bank is the outside of the slight bend) (Figure 2, Photograph 1). The river is confined within a 60 m wide valley (top width) and there are no floodplains. The south valley slope is about 5 m high and the north valley slope is about 10 m high. The bankfull depth and width are approximately 2.5 m and 20 m, respectively, measured at the 1:2-year high-water-mark.

A WSC gauge is located immediately upstream of the bridge on the left (north bank). There is a riffle 50 m downstream of the bridge that hydraulically controls the river level at the bridge and the WSC gauge (Figure 2, Photographs 3 and 6).

The flow regime of the Jean Marie River is that the lowest flow occurs in late winter just before spring melt and the annual high flows typically occur in the spring during snow melt. Snow melt typically begins around the beginning of April and continues through to June. Extreme flood flows occur due to precipitation events, which can occur during spring and combine with snow melt, or occur later in the summer when the snow has melted. The stream-flow response to precipitation is buffered by lake storage.

The flood of record on the Jean Marie River occurred in July 1988 as the result of a precipitation event. Extreme flooding occurred during this time throughout the southwest portion of the Northwest Territories, specifically in the Liard River and Mackenzie River basins (Public Safety Canada 2013).

3.1 Observations during the September 27 and 28 Site Reconnaissance

Matrix performed a site visit on September 27 and 28, 2023. The river was clear of ice and the provisional flow at the WSC gauge was 0.46 m^3/s, allowing for visual observations of the existing riprap and river bed substrate beneath the bridge (Figure 2, Photographs 3 to 5). The following key observations were made:

- At the bridge, the river substrate is rocky. The D_{50} is at least 200 mm underneath the bridge (Figure 2, Photographs 4 and 5).

- Downstream of the bridge, where the river widens, the D_{50} on the gravel bar is smaller, around 50 mm. This D_{50} reflects the material size that the river can transport through the bridge opening (Figure 2, Photographs 6 and 8).

- Riprap at the existing bridge is the upper end of Class II, greater than 600 mm (Figure 2, Photographs 3 and 4). The riprap has been stable for past 60 years, it is not cracked or otherwise deteriorated. The smaller and medium sized rocks in the Class II gradation are lacking; this can have the effect of increasing the mobilization of fines from beneath the riprap (due to larger voids in the riprap revetment compared to a well graded riprap revetment). There are some localized voids in the riprap, suspected to be from loss of fines in the underlying material and/or ice plucking.

- The debris pile on the outside river bend downstream of the bridge, where the river widens, was mostly comprised of relatively small diameter trees (<0.5 m diameter), but there were a few large trees with maximum tree diameters of about 0.9 m (Figure 2, Photographs 6 and 7).

4 HISTORICAL AERIAL PHOTOGRAPH ANALYSIS

Figure 3 shows the aerial photograph comparison. Key observations are summarized on Figure 3 and below.

- The river and river banks are stable within the 1,200-m long reach shown on Figure 3 except for erosion 150 m downstream of the bridge as described in the next bullet. The rating curve at the bridge has remained stable based on the WSC rating curves from 1972 to 2022 including before and after the 1988 flood of record.

- Erosion and widening of the river have occurred about 150 m downstream of the bridge. No erosion was observed in 1968 or 1978, whereas erosion was observed in 1994 and 2022 (after the flood of record in 1988).

- Some trees, about 10 m long, have accumulated in the bend downstream of the bridge approximately 150 m.

5 HYDROTECHNICAL DESIGN

5.1 Hydrology and Design Flood

Figure 4 summarizes the hydrologic analysis completed for this hydrotechnical assessment.

A flood frequency analysis was completed on annual maximum instantaneous flows from WSC station 10FB005 Jean Marie River at Highway 1. When maximum instantaneous flows were not available, they were estimated from the annual maximum daily average flow by applying the best fitted linear regression ratio of maximum instantaneous to daily average flow (1.016). This resulted in a total maximum instantaneous flow record of 47 years, of which 12 years (26%) were estimated. One year of partial data, in 1980, was excluded. There is a high degree of certainty in the estimated maximum instantaneous flows because of the small ratio between maximum instantaneous and daily average flow.

Several probability distributions were evaluated using Hyfran Version 2.2 software as shown on Figure 4. The Generalized Extreme Value distribution (maximum likelihood) is the best fitted distribution and is recommended for the design because it is reasonably conservative compared to most other distributions. This results in a 1:100-year peak instantaneous design flood of 210 m^3/s which is similar to the flood of record (216 m^3/s).

For comparison, the previous Stantec study computed a 1:100-year peak instantaneous flood of 258 m^3/s using the 35 years of annual maximum instantaneous flows and a lognormal distribution (maximum likelihood).

Consideration for climate change is included in the recommended design freeboard, discussed in the section on vertical freeboard.

5.2 Hydraulic Modelling and Design Water Level and Velocity

The WSC rating curve was used to determine the design water levels at the bridge. The WSC gauge is located 40 m upstream of the bridge, with negligible difference in water level between the bridge and the WSC gauge (the design flood water profile has a gradient of 0.01%). The WSC rating curve includes a water level and flow measurement at the design flood (measurement at 211 m^3/s vs. the design flow of 210 m^3/s).

A hydraulic model was developed to assess the site hydraulics and determine the design velocity. The hydraulic model was developed using HEC-RAS hydraulic modelling software (Version 6.3.1). Three models were created, one for existing bridge conditions and two for the two proposed bridge options (single-span and three-span). The hydraulic model and input parameters are summarized below:

- The model was developed from the 2019 survey data by Stantec. The terrain along the top of the valley slope was estimated at 10 out of 13 of the cross-sections using NRCAN terrain data.
    - The majority of the flow is contained within the 2019 survey data and thus the model results are not sensitive to differences in the estimated terrain data.
- The model domain extends over the surveyed reach from 150 m upstream to 80 m downstream of the bridge.
- The expansion and contraction coefficients for the two cross-sections upstream and downstream of the existing bridge and proposed bridge options were conservatively set to values for typical bridges

(i.e., 0.3 and 0.5, respectively). The expansion and contraction coefficients had negligible effect on the model results (see sensitivity analysis).

- Values for Manning's roughness coefficients (*n*) were selected based on a review of site photographs and suggested values by Chow (1959). The selected Manning's *n* values were 0.03 within the channel (below the vegetation at about the 1:2-year flood), and 0.15 above the vegetation. The vegetation line is at an elevation of about 202 m (about 2 to 2.5 m above the riverbed) which is roughly the 1:2-year water level. The Manning's roughness coefficients had negligible effect on the model results (see sensitivity analysis).

- The downstream boundary condition was set to a rating curve equal to the WSC rating curve offset by -0.25 m, i.e., the WSC was lowered. The offset was determined by adjusting the offset value until the rating curve computed by the model at the WSC gauge (40 m upstream of the bridge) closely matched the WSC rating curve (see Figure 4).

- Subcritical flow regime calculations were used, and the model results confirmed subcritical conditions (i.e., the computed Froude number was less than 1).

The computed rating curve (water level vs. flow) at the bridge and the WSC rating curve are shown on Figure 4. The computed 1:100-year design water level is 205.1 m. The computed 1:100-year design velocity is 2.1 m/s, taken as the maximum average channel velocity near the bridge (occurs immediately downstream of the bridge). The rating curve, design water level, and velocity apply to the existing bridge and proposed bridge options.

5.2.1 Sensitivity Analysis

A sensitivity analysis was conducted to determine the effects of changing key model parameters and inputs. The results are summarized in Table 1. The range of conditions tested had negligible effect on the hydraulic model results.

TABLE 1 Hydraulic Model Sensitivity Analysis

Parameter	Parameter Variance (or Value)	Effect on 1:100-year Design Flood Level (m)	Effect on 1:100-year Design Flood Velocity (m/s)
Manning roughness coefficient (*n*)	-20% to +20%	-0.02 to + 0.03	<0.01
Contraction / expansion coefficients	0.1 / 0.3 to 0.6 / 0.8	-0.02 to + 0.03	<0.01
Bridge Condition	Existing Proposed Single-Span Proposed Three-Span	- <0.01 <0.01	- <0.01 <0.01

A scenario was also modelled for a debris blockage 10 m wide × 3 m high on the north pier which caused the water level to increase by 0.12 m. This is considered an extreme case because the design flood is only about 3 m deep at the north pier and it is not typical to have debris blockage all the way down to the riverbed.

5.3 River Ice

The pier design (if the three-span option is reconsidered in the future) must consider river ice forces. River ice does not govern the bridge elevation.

5.3.1 Design Ice Level and Thickness

River ice processes are complex and depend on river and weather conditions (hydro-climatic conditions). The primary factors governing ice growth and type are: air temperature, flow, velocity, and the open water portion of flow (ice growth slows as ice cover shelters the water from the cold air). The Jean Marie River at the bridge is slow and thus it is suspected that it freezes over as a thermal ice cover, not as frazil. The primary factors governing ice melt and break up are: air temperature, flow, velocity, ice thickness and strength, and bank conditions and geometry.

The river ice hydro-climatic assessment is shown on Figure 5 and included an analysis of climate data and relevant WSC records, including freeze-up and break-up dates, daily average recorded winter flow (available from 1973 to 2022), daily average recorded winter water levels (available from 2002 to 2019), manual winter flow and water levels (available from 1996 to 2022), and four WSC ice thickness measurements (available from 2016 to 2019). Ice thicknesses measured by WSC ranged from a low of 0.15 m in December 2018 to a high of 0.54 m in April 2018. Approximate ice thicknesses measurements from 2002 to 2019 can be gleaned from the top right chart on Figure 5, which compares the recorded winter stage values to the open water rating curve.

A 1:100-year design ice thickness of 0.7 m was computed:

- Using an equation for thermal ice growth (Hicks 2016) that is based on the annual Cumulative Degree Days Freezing[2] (CDDF). An ice growth coefficient was calculated for each of the four recorded manual ice thickness measurement by WSC and the maximum coefficient was selected (bottom left graph on Figure 5). The selected value of 0.011 compares well to typical values of 0.007 to 0.014 in literature for sheltered streams (Hicks 2016).
    - A 1:100-year maximum CDDF of 4,000°C-days was computed from a frequency analysis of the maximum annual CDDF from a 58-year record from 1963 to 2021 from the Environment Canada weather station at Fort Simpson (Climate ID 2202103). See the bottom charts on Figure 5.

[2] Cumulative Degree Days Freezing (CDDF) is a common climatic parameter used to summarize air temperature and assess river ice formation, growth, and thickness. It is calculated as the rolling sum of daily average temperatures below 0°C.

- The design ice thickness is conservative because the maximum annual CDDF is trending lower over the period of record, indicating warmer winters, as shown on Figure 5.

- A design top of ice elevation of 203.0 m is recommended based on the following:

  - The thickest and strongest ice occurs at flows around 10 m^3/s or less, as shown on the top right chart of Figure 5 (comparing winter stage measurements to the open water rating curve). Ice thickness decreases for higher flows which occur later in the spring when ice has begun melting.

  - As shown on Figure 5, for the period 2002 to 2019 and for flows less than 10 m^3/s, the maximum winter stage occurred in April 2007. The stage was 202.1 m on April 29, 2007 (approximately equal to the top of ice which typically floats with about 92% of it's thickness submerged; Hicks 2016). Using the equation for thermal ice growth (Hicks 2016) and the CDDF of 2,891°C-days for this day, the ice thickness is calculated as 0.6 m (see top right chart on Figure 5).

  - Flows during the four manual ice measurements were less than 1 m^3/s. The maximum manual measured ice thickness from the four measurements was 0.54 m, with a measured stage of 200.9 m and a flow of 0.6 m^3/s.

  - For design purposes, a maximum top of ice elevation of 203 m is recommended which provides a reasonably conservative 1 m contingency above the April 2007 stage. If higher ice levels occur, they will likely have significantly lower ice thickness and strength compared to the design ice thickness and strength values per the bullets above and the rating curve.

5.3.2 Design Ice Forces

5.3.2.1 Thermal Expansion Loading

Thermal expansion loading occurs when a continuous/solid ice sheet is formed between structural elements, such as between bridge piers. The abutments are located 1.5 to 2.3 m above the design ice level and will not be exposed to river ice forces. For the three-span bridge option, the proposed bridge piers are circular and small (0.6 m diameter) compared to the 20 m span length between piers, therefore thermal ice loading is not expected on the bridge piers.

5.3.2.2 Ice Impact (Dynamic Force)

Ice impact on the pier can occur during break-up. The *Canadian Highway Bridge Design Code* (CSA 2019, Clause 3.12.2.1) recommends the following crushing strengths based on climatic conditions during break-up:

- the ice breaks up at melting temperature and is substantially disintegrated: 400 kPa
- the ice breaks up at melting temperature and is somewhat disintegrated: 700 kPa

- the ice breaks up or ice movement occurs at melting temperature and is internally sound and moving in large pieces: 1,100 kPa
- the ice breaks up or ice movement occurs at temperatures considerably below the melting point of the ice: 1,500 kPa

A crushing strength of 1,100 kPa is recommended for this bridge (i.e., the ice breaks up or ice movement occurs at melting temperature and is internally sound and moving in large pieces per the CSA Bridge Design Code Section 3.12.2.1) because break-up occurs after several days of positive temperatures, and with increasing water level and flow.

For example, in 2007, break-up occurred during April (started sometime before April 24 and was fully broken up by April 29), with peak ice levels occurring on April 29. Flow increased from 0.36 m^3/s on April 24 to 8 m^3/s on April 29 and continued to rapidly increase to a peak of 50 m^3/s on May 5. The average air temperature was 4°C the week before flow began increasing, i.e., the week before April 24.

The greatest ice thickness, as previously discussed, likely occurred at break-up on April 29 (i.e., the ice was likely internally sound and moving in large pieces during break-up).

5.4 Vertical and Horizontal Clearance

5.4.1 Vertical Clearance (Freeboard) – Hydrotechnical

The existing bridge provides 0.4 m of freeboard above the 1:100-year design flood. From a hydrotechnical perspective, Matrix recommends a minimum freeboard of 0.9 m, which provides 0.5 m more freeboard than the existing bridge to account for potential increases to the 1:100-year flood due to climate change. The Canadian Highway Bridge Design Code recommends 1.0 m as a starting point for freeboard, but this can be lowered or optimized to meet the design condition for a number of reasons (CSA 2019). Relevant reasons to the project site include high degree of confidence in the design high water level and the bridge is on a longitudinal grade, where most of the bridge has more than 1.0 m freeboard (CSA 2019).

This recommendation by Matrix is based on the following.

- The existing bridge has 50+ years of proven performance with no indication of damage during the 1988 flood of record, which was slightly higher than the 1:100-year flood (i.e., there was 0.4 m of freeboard during the flood of record).

- There is high confidence with the 1:100-year flood flow rate because it is based on a long period of record (47 years), and because the 1988 flood of record was a similar magnitude to the 1:100-year flood.

- There is high confidence with the 1:100-year water level because the WSC gauge is located immediately upstream of the bridge and a water level was measured by WSC during the flood of record.

- Providing 0.5 m of freeboard for potential climate change; based on the most conservative estimate:
  - EGBC recommends a climate change factor of 10% to 20%, with 10% justifiable if there are no historical trends (EGBC 2018). There is no statistically significant trend in the historic flood data on Jean Marie River, therefore 10% is justifiable:
    - A 10% increase to the 1:100-year flood flow would increase the water level by 0.3 m.
  - The worst-case projections for climate change show a 15% increase in the 1:100-year precipitation in the Jean Marie watershed (Western University, Canadian Rainfall Intensity Duration Frequency tool).
    - A 15% increase to the 1:100-year flood flow would increase the water level by 0.5 m.

5.4.2 Vertical Clearance (Freeboard) – Selected Design

The bridge design proposed by Jacobs will provide a minimum 1.2 m freeboard at the south abutment.

The bridge and highway will be on a sloping grade across the river, of 1.25% with the higher elevation at the north bank. The minimum recommended freeboard of 1.2 m applies at the south abutment where the bridge will have the lowest elevation.

The north abutment is located on the outside bend of the river. Therefore, any floating debris will tend towards the north where additional freeboard will be provided due to the bridge grade. For the three-span option, about 0.5 m of additional freeboard will be provided at the north pier, which is deemed adequate for potential debris blockage (a debris jam was modelled which resulted in a 0.12 m water level increase, see model sensitivity analysis results).

5.4.3 Clearance for Navigation (Vertical and Horizontal)

Figure 6 shows a summary table of the proposed and existing bridge clearances. From the minimum low chord elevation, the proposed bridge will provide:

- 0.8 m more freeboard than the existing bridge
- 1.2 m freeboard to the 1:100-year water level
- 1.9 m freeboard to the 1:50-year water level
- 2.5 m freeboard to the 1:20-year water level
- 4.2 m freeboard to the 1:2-year water level

A vertical clearance of 1.7 m is typically considered adequate for rafts, kayaks, and canoes and is typically measured from the 1:2-year or 1:20-year water level (based on Matrix's experience with Transport Canada applications).

With respect to horizontal clearances:

- The existing bridge provides a clear-span horizontal clearance of 35 m.
- The proposed clear-span bridge option will provide a clear-span horizontal clearance of 37.4 m.
- The proposed three-span bridge will provide a horizontal clearance of 20 m between the piers.

Considering that a 3-person canoe is about 5.5 m long, the horizontal clearance of 20 m is adequate for navigation.

5.5 Design Scour

Scour was assessed for the bank riprap design (re: the need for an apron) and the pier design (for the 3-span bridge option).

5.5.1 Channel Scour

Channel scour was computed from general scour (computed via the Blench Regime Method) times the straight channel local scour multiplier (represented by the Z-factor) to account for the river curvature (FHWA 2012). Inputs to the scour calculations are discharge, channel geometry, the median bed size (D_{50}), and the Z-Factor.

Based on the September 2023 site visit, the D_{50} of the riverbed substrate at the bridge is 200 mm (Figure 2, Photograph 4). A Z factor of 1.5, representing a moderate bend, is recommended based on the current river alignment and based on the historical air photo review (Figure 3). Scour calculations with these inputs resulted in a negative scour value, i.e., no additional net scour relative to the current thalweg of the river. Therefore, a design channel scour depth elevation of 199.7 m (elevation of thalweg) is recommended. These results conform with the hydrotechnical field observations during the site visit in September 2023.

5.5.2 Local Pier Scour

The theoretical computations for local pier scour (if the three-span bridge option is reconsidered in the future) primarily depend on the pier diameter and do not depend on the bed material size. The theoretical local pier scour is summarized below:

- Pier scour was computed for the proposed pier pile design, consisting of steel pipe piles, each with a diameter of 0.6 m. The piers are aligned with the flow direction, thus scour calculations are not dependant on the number of piles per pier.

- The flow depth upstream of the piers was set to 3.2 m, which corresponds to the local water depth at the piers during the design flood from the hydraulic model results.

- A local scour depth of 1.4 m was computed using the Colorado State University (CSU) equation (FHWA 2012). Note that the CSU method does not depend on the bed material size and is conservatively based on the upper envelope of a data set of measured scour depths at bridge piers.

- A scour depth of 0.7 m was computed using the Transportation Association of Canada modified Melville method (TAC 2001). The calculation assumed the maximum sediment size factor of 0.5 based on the median bed material size of 200 mm. Note that the Melville method is also conservatively based on the upper envelope of a data set of measured scour depths at bridge piers.

Since no channel scour is expected (per above section), a total pier scour depth of 1.4 m is recommended, which corresponds to a design scour elevation of 198.3 m. An additional factor of safety is not recommended because the theoretical computations are conservative.

5.6 Erosion and Scour Protection

5.6.1 Riprap Sizing

The minimum required riprap size was computed using an empirical method developed by the United States Army Corps of Engineers (USACE 1991) and recommended in the *Riprap Design and Construction Guide* (B.C. MELP 2000) and Transportation Association of Canada's *Guide to Bridge Hydraulics* (TAC 2001). The computed minimum median riprap diameter was 165 mm for rounded riprap which is equivalent to Alberta Class 1M riprap (D_{50} = 175 mm). Riprap should meet the GNWT *Specifications for Bridge Construction, Section 10 Heavy Rock Riprap* (GNWT 2021), which provide minimum durability, hardness, and density requirements.

The design velocity calculated immediately downstream of the bridge is 2.1 m/s. The maximum permissible velocity for Class 1M riprap is 2.2 m/s and 3.0 m/s for Class 1 (AT 2003b). Thus, we recommend using Class 1 riprap (D_{50} = 300 mm) or larger.

As described in Section 3.1, The existing rounded riprap at the bridge is predominantly comprised of the higher end of Class 2 riprap (e.g., 600 to 800 mm diameter, as shown on Photograph 5 on Figure 2). The riprap extends approximately 8 m upstream and downstream of the bridge (Figure 2, Photograph 3). The riprap is not cracked or otherwise deteriorated (Figure 2, Photographs 3 and 5). There are no records that riprap repairs have been required at the bridge and the riprap appears to be original (i.e., it has been stable for 60 years). The Stantec hydrotechnical report noted that 1992 photographs showed erosion of fill adjacent to the bridge abutments – it is not clear if this involved riprap erosion or displacement. This erosion was not observed during the Matrix site visit in September 2023. Some localized voids were observed in the riprap.

5.6.2 Riprap Design

The following riprap design is recommended:

- Class 1 (D_{50} = 300 mm) angular riprap is adequate based on riprap calculations by Matrix. The existing riprap is Class 2 and can be re-used, with some augmentation, for the new bridge.
    - The minimum riprap revetment thickness is 2 × D_{50}, which corresponds to 0.6 m thick for Class 1 riprap and 1 m thick for Class 2 riprap.
- Riprap should be used to protect the abutments, the road fill, and the adjacent banks from scour and erosion. Riprap should be installed at a 2H:1V slope or flatter, which is best practice for stability of riprap.
- The top of the riprap should be 0.3 m above the 1:100-year water level.
- Based on the scour calculations and observations by Matrix in September 2023, the existing riprap toe is adequate to resist undermining due to scour (i.e., a riprap launching apron is not required).
- Work to be completed during the low water period(s). There shall be no placement of material in the water. All material thicknesses specified are measured perpendicular to the slope.
- The general layout drawing has been prepared for Class 2 riprap (Jacobs 2023):
    - Top Portion (Above the 1:2-year WL of 202.1 m to the top of riprap elevation of 205.4 m for both abutments): Use a combination of salvaged existing riprap and imported riprap underlain by 200 mm thick granular filter base. If Class 1 gradation is used, it shall be preferentially placed at the top of the riprap revetment (i.e., where flow velocity is the lowest). If existing riprap is salvaged, it may need to be blended with smaller riprap, cobbles, and gravels to meet the full Class II gradation, to the satisfaction of the hydrotechnical engineer. Granular filter base material shall be approved either as well graded crushed granular material with D100 of 100 to 150 mm or equivalent well graded uncrushed bank pitrun gravel. The contractor shall submit the proposed material for approval by the hydrotechnical engineer at least 2 weeks prior to the works.
    - Mid Portion (Below the 1:2-year WL of 202.1 m and above the water level at the time of construction): Add smaller pieces of riprap, cobbles, and gravels to the voids of the existing riprap surface to approximately meet the Class II gradation, to the satisfaction of the hydrotechnical engineer.
    - Bottom Portion (Below the water level at the time of construction): No work below the water level at the time of construction.

- For the abutments and piles, security against scour failure should be built into the substructure design and should not depend heavily on riprap (TAC 2001).
    - The pile cap designed by Jacobs appears to be above the 1:100-year water level (i.e., much higher than the scour level), but from a hydrotechnical perspective there is low risk of failure due to the low flow velocity and the low probability of debris accumulating or impinging on the abutment.
- For the piers, if the multi-span bridge option is reconsidered, the pile cap should be deeper than the pier scour design depth elevation 198.3 m and riprap should not be relied upon to protect the piers against scour, per the CHBDC and TAC.

  Riprap is still recommended all-around the piers for best practice.

5.7 Summary of Recommended Hydrotechnical Design

The recommended hydrotechnical design criteria are provided in Table 2.

TABLE 2 Recommended Hydrotechnical Design Criteria for the Proposed Highway Bridge

Parameter	Value	Comment
Design Flood and Freeboard		
Flood return period	1:100-year	As per GNWT Project Requirements
Design flow[1,2]	210 m^3/s	As per analysis of 47 years of instantaneous flow data
Design water level[2]	205.1 m	As per WSC Rating Curve
Design Velocity[2]	2.1 m/s	As per hydraulic model
Minimum freeboard[2,3]	0.9 m	0.5 m greater than the existing bridge, which had 0.4 m clearance during the 1988 flood of record
Minimum bridge low chord elevation[3]	206.0	
Design River Ice		
Top of ice elevation	203 m	As per assessment of 18 years of recorded ice levels including a 1 m contingency
Ice thickness	0.7 m	As per computed 1:100-year design ice thickness calibrated to four measured ice thicknesses from 2016 to 2019
Crushing strength	1,100 kPa	As per CSA CHBDC assessment of weather, ice level, and flow during break-up periods
Design Scour		
Scour for riprap design (depth/elevation)	0 m/199.7 m (thalweg)	As per theoretical scour calculations and based on the measured D50 of 200 mm at the bridge.
Pier Scour (depth/elevation)	1.4 m/198.3 m	As per theoretical local pier scour computations.
Erosion and Scour Protection		
Riprap	Class 1 Angular and Class 2 Angular[4]. Class 1 riprap shall be 0.6 m thick and Class 2 riprap shall be 1.0 m thick.	Class 1 riprap is adequate as per riprap sizing computations. Existing riprap is Class 2 and can be re-used. Per the Design Scour section, a riprap toe apron is not required to protect against undermining due to scour.

Notes:

1. The design flow is the instantaneous peak flow.
2. The 1:100-year design flow, water level, and velocity do not include climate change. Consideration for climate change is included in the freeboard.
3. From a hydrotechnical perspective a minimum freeboard 0.9 m above the 1:100-year design flow is deemed to be fully adequate as it provides 0.5 m more clearance than the existing bridge to account for potential increased flood flow due to climate change. The existing bridge had 0.4 m clearance during the 1988 flood of record, which was slightly greater than the 1:100-year event. The proposed bridge design by Jacobs provides a minimum freeboard of 1.2 m.
4. Angular rock to be used for riprap per GNWT Standard Specifications for Bridge Construction, Section 10.3.

6 REFERENCES

Alberta Transportation (AT). 2020a. *Bridge Conceptual Design Guidelines*. Version 3.0. Technical Standards Branch. May 2020.

Alberta Transportation (AT). 2007. *Design Bulleting #45/2007: Use of Retaining Wall Structures for Bridges and Roadways In Active Watercourse Environments*. February 2007.

Alberta Transportation (AT). 2003a. *Best Practice Guideline #7: Spread Footings*. Adopted May 1, 2003. January 2003.

Alberta Transportation (AT). 2003b. *Appendix F, Guidelines for Design of Open Channels*. March 18, 2003. http://www.transportation.alberta.ca/content/doctype372/production/erosionappf.pdf

British Columbia Ministry of Environment, Lands and Parks (B.C. MELP). 2000. *Riprap Design and Construction Guide*. Public Safety Section, Water Management Branch. March 2000. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/riprap_guide.pdf

Canadian Standards Association (CSA). 2019. *CSA S6:19 Canadian Highway Bridge Design Code*. Supersedes the previous editions published in 2014, 2006 (including three supplements published in 2010, 2011, and 2013), 2000, 1988, 1978, 1974, 1966, 1952, 1938, 1929, and 1922. 2019. https://www.csagroup.org/canadian-highway-bridge-design-code/

Chow. 1959. *Manning's n for Channels*. 1959. http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

CSA Group. 2017. *Canadian Highway Bridge Design Code*. Reprinted July 2017. This reprint is being issued to incorporate Update No. 1 (April 2016) and Update No. 2 (July 2017) into the original 2014 Code. Mississauga, Ontario. July 2017.

Engineers and Geoscientists British Columbia (EGBC). 2018. "Natural Hazards: Legislated Flood Assessments in a Changing Climate in BC." Addendum to *Professional Practice Guidelines*. British Columbia. August 28, 2018.

Faria D.A. 2002. *Overview of the Hydrology in the Deh Cho Region - NWT*. Prepared for Water Resources Division, Indian and Northern Affairs Canada. Yellowknife, Northwest Territories. August 2002.

Federal Highway Administration (FHWA). 2012. *Evaluating Scour at Bridges: Fifth Edition*. US Department of Transportation. Fort Collins, Colorado. April 2012.

Government of Northwest Territories (GNWT). 2021. *Standard Specifications for Bridge Construction*. Edition 1. Prepared by Associated Engineering. 2021. https://www.inf.gov.nt.ca/sites/inf/files/resources/gnwt_ssbc_ed_1_2021_final_1.pdf

Government of Northwest Territories (GNWT). 2022a. *Request for Proposals: Architectural and Engineering Services, Procurement Shared Services, Jean Marie River Bridge Replacement Engineering Services*. Event ID: 0000005729. July 29, 2022.

Government of Northwest Territories (GNWT). 2022b. *Design Criteria/Standards: Bridges and Bridge Culverts*. April 7, 2022.

Government of the Northwest Territories (GNWT). 2023. *Design Exceptions - Freeboard Reduction*. Prepared for Jacobs. April 20, 2023.

Hicks F.E. 2016. *An Introduction to River Ice Engineering: For Civil Engineers and Geoscientists*. CreateSpace Independent Publishing Platform. ISBN: 1-4927-8863-5. 2016. 170 pp.

Jacobs. 2023. *Government of Northwest Territories, Bridge Project, No. SC-INF01-6081-2023, Jean Marie River Bridge, Highway No. 1 (Mackenzie Highway) km 411.2*. Issued for 50% Review. 2023.

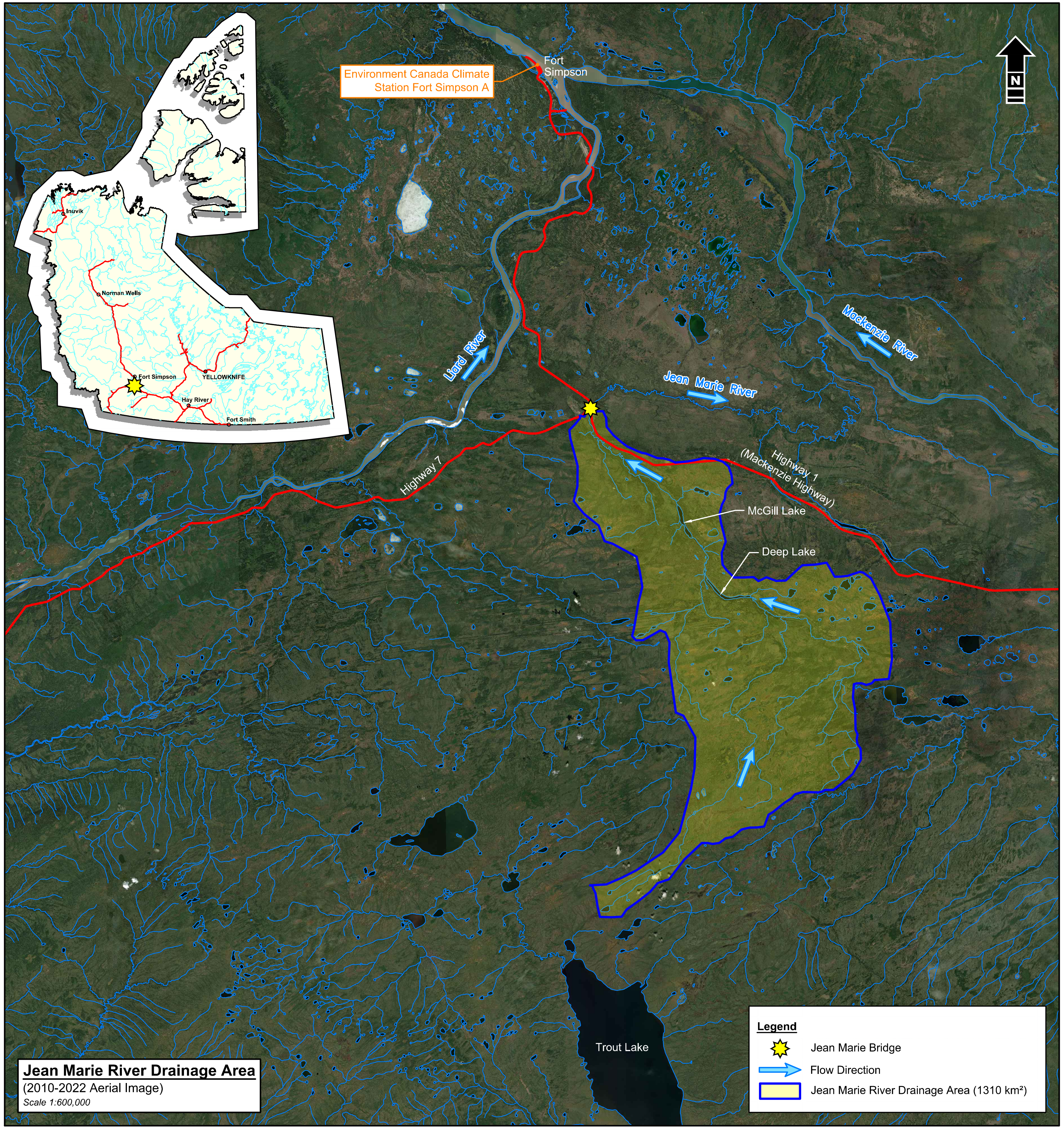
Public Safety Canada. 2013. *Canadian Disaster Database Search Results*. Date modified September 12, 2013. Date accessed April 14, 2023. https://cdd.publicsafety.gc.ca/dtpg-eng.aspx?cultureCode=en-Ca&eventTypes=%27FL%27%2C%27TO%27%2C%27WF%27%2C%27SW%27%2C%27EQ%27&normalizedCostYear=1&dynamic=false&eventId=90

Stantec Consulting Ltd. (Stantec). 2019. *Jean-Marie River Bridge Hydrotechnical Assessment Report*. Prepared for Government of the Northwest Territories, Transportation Division, Department of Infrastructure. December 16, 2019.

Transportation Association of Canada (TAC). 2021. *Guide to Bridge Hydraulics*. Third Edition. Last updated January 2021. https://www.tac-atc.ca/en/projects/progress/guide-bridge-hydraulics-third-edition

Transportation Association of Canada (TAC). 2001. *Guide to Bridge Hydraulics*. June 15, 2001.

United States Army Corps of Engineers (USACE). 1991. *Hydraulic Design of Flood Control Channels*. Engineer Manual 1110-2-1601. Department of the Interior. Washington, DC. July 1991.



Jean Marie River Drainage Area
(2010-2022 Aerial Image)
Scale 1:600,000

Area Near Bridge
(2019-2022 Aerial Image)
Scale 1:15,000

Existing Jean Marie River Bridge (2023)

References:

1. Roads and Hydrography obtained from GeoGratis © Department of Natural Resources Canada (all rights reserved) used under license.
2. Aerial imagery (2010-2022 and 2019-2022) obtained from ESRI Imagery © (2023) used under license
3. Photograph by Matrix, September 28, 2023.

1 : 15,000 metres
150 0 150 300
UTM83-10

1 : 600,000 metres
6000 0 6000 12000
UTM83-10

Note: Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

Matrix Solutions Inc.
A Montrose Environmental Company

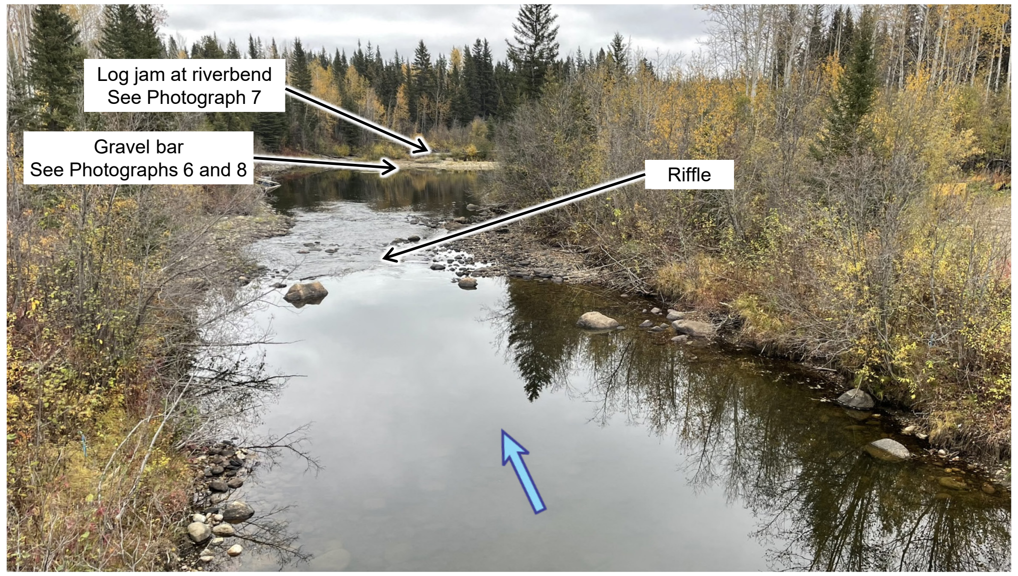
Government of the Northwest Territories and Jacobs
Jean Marie River Bridge Replacement - Highway 1 (Mackenzie Highway)

Location Plan

Date:	Project:	Submitter:	Reviewer:
January 2024	35370-522	T. Schaepsmeyer	K. Curtis

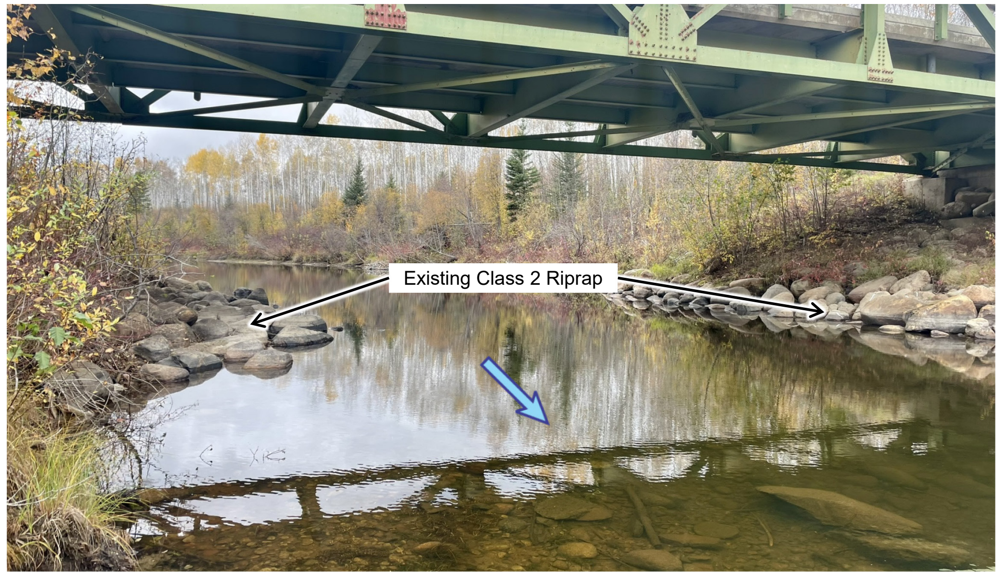
Figure 1

Photograph 1: River immediately upstream of the bridge.

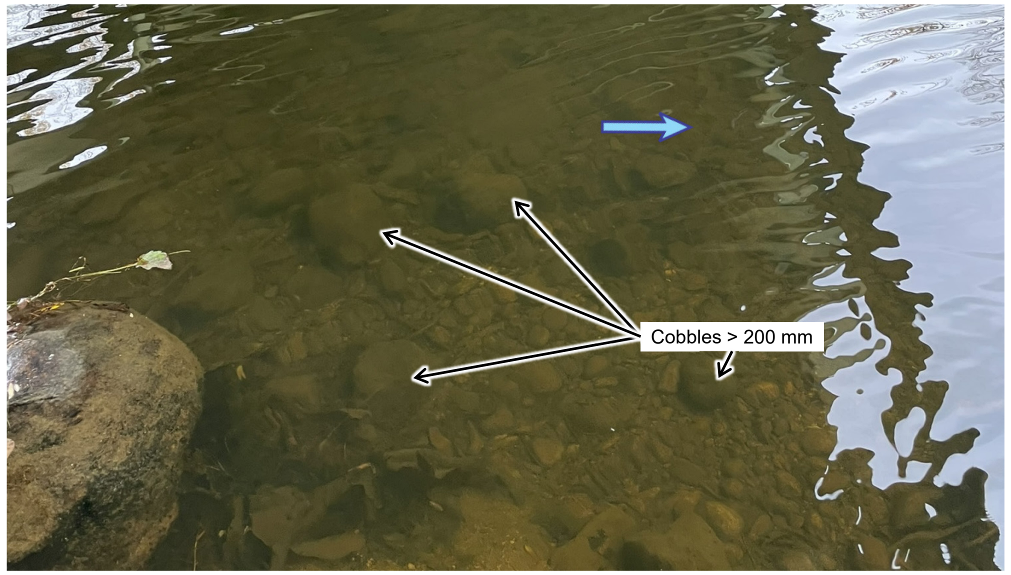


Photograph 2: River immediately downstream of the bridge.

Photograph 3: River at the bridge.



Photograph 4: Conditions below the bridge.



Photograph 5: The rocky river substrate directly beneath the bridge. Large (D50 > 200mm) cobble substrate visible.

Photograph 6: The river approximately 200 m downstream of the bridge. The river widens from approximately 25 m to 60 m at this location (Figure 3 Note 2). Log jam present at the sharp bend in the upper right.

Photograph 7: Log jam present at the downstream of the bridge. The largest log observed had a diameter of 0.9 m (Figure 3 Note 3).

Photograph 8: The gravel bar downstream of the bridge (D_{50} about 100 mm).

Legend

Flow Direction

(A) Inset Photograph Location

Notes:

1. Photographs taken by K. Curtis, P.Eng., Matrix Solutions Inc. on September 27, 2023.
2. Figure(s) must be used in conjunction with the attached report and is (are) subject to the limitations and conditions stated in the report.
3. On the September 27, 2023 WSC recorded a provisional flow of 0.46 m^3/s.

Matrix Solutions Inc.
A Montrose Environmental Company

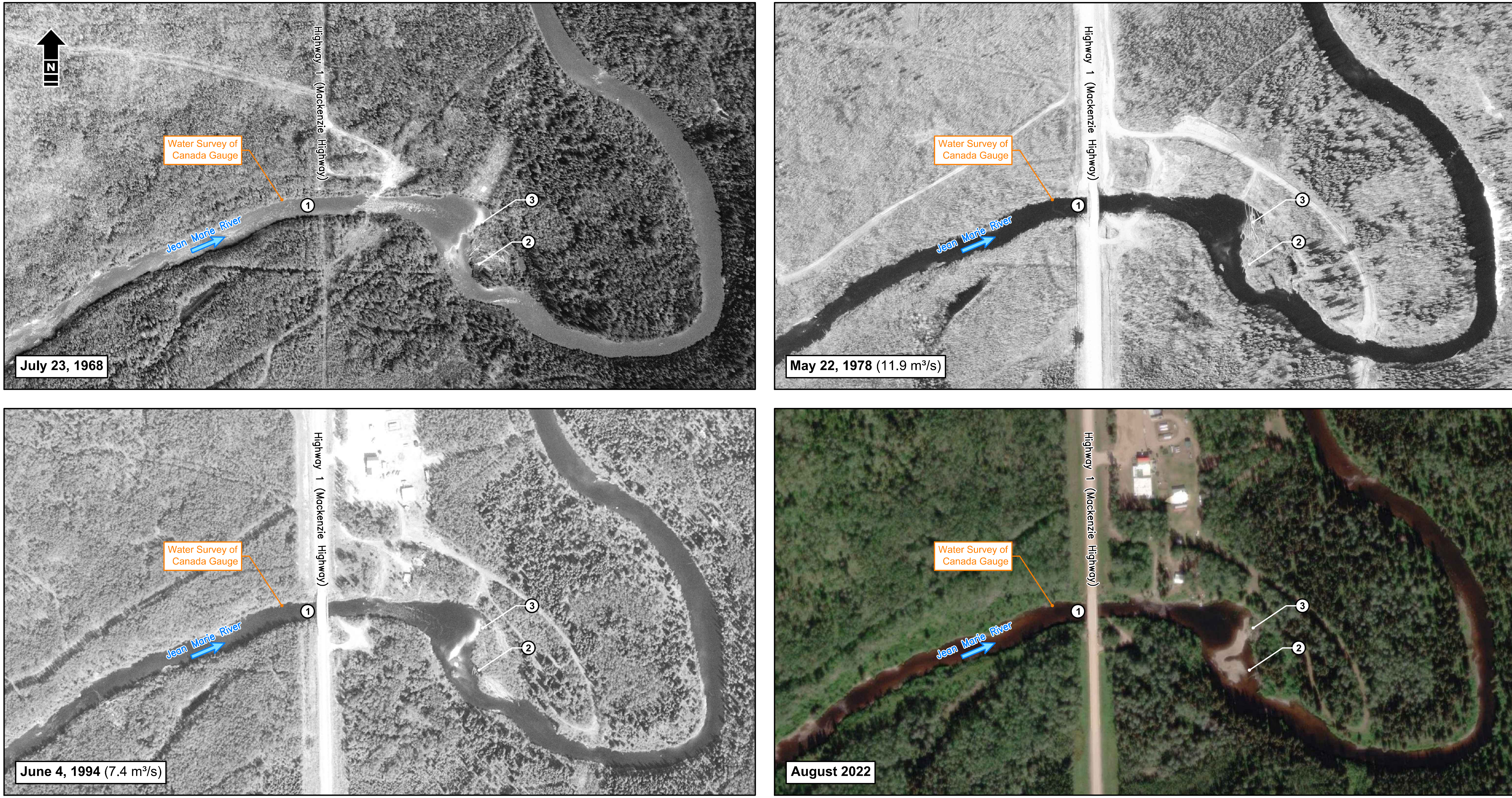
Government of the Northwest Territories and Jacobs

Jean Marie River Bridge Replacement – Highway 1 (Mackenzie Highway)

September 27, 2023
Site Photographs

Date: January 2024	Project: 35370-522	Submitter: M. Schlumpf	Reviewer: T. Schaepsmeyer

Figure 2



Notes:

1. The river and riverbanks are stable within the reach shown except 150 m downstream of the bridge (see note 2). The rating curve at the bridge has remained stable based on the WSC rating curves from 1972 to 2022 including before and after the 1988 flood of record.
2. Erosion and widening of the river have occurred about 150 m downstream of the bridge. No erosion was observed in 1968 or 1978, whereas erosion was observed in 1994 and 2022. The flood of record occurred in 1988.
3. Some trees, about 10 m long, have accumulated in the bend downstream of the bridge.

References:

1. Aerial imagery (August 2019 to August 2022) obtained from ESRI Imagery © (2023) used under license.
2. Historical aerial imagery (1968, 1978, and 1994) obtained from the National Air Photo Library (2023).

1 : 4,000 metres
40 0 40 80
UTM83-10

Note: Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

Matrix Solutions Inc.
A Montrose Environmental Company

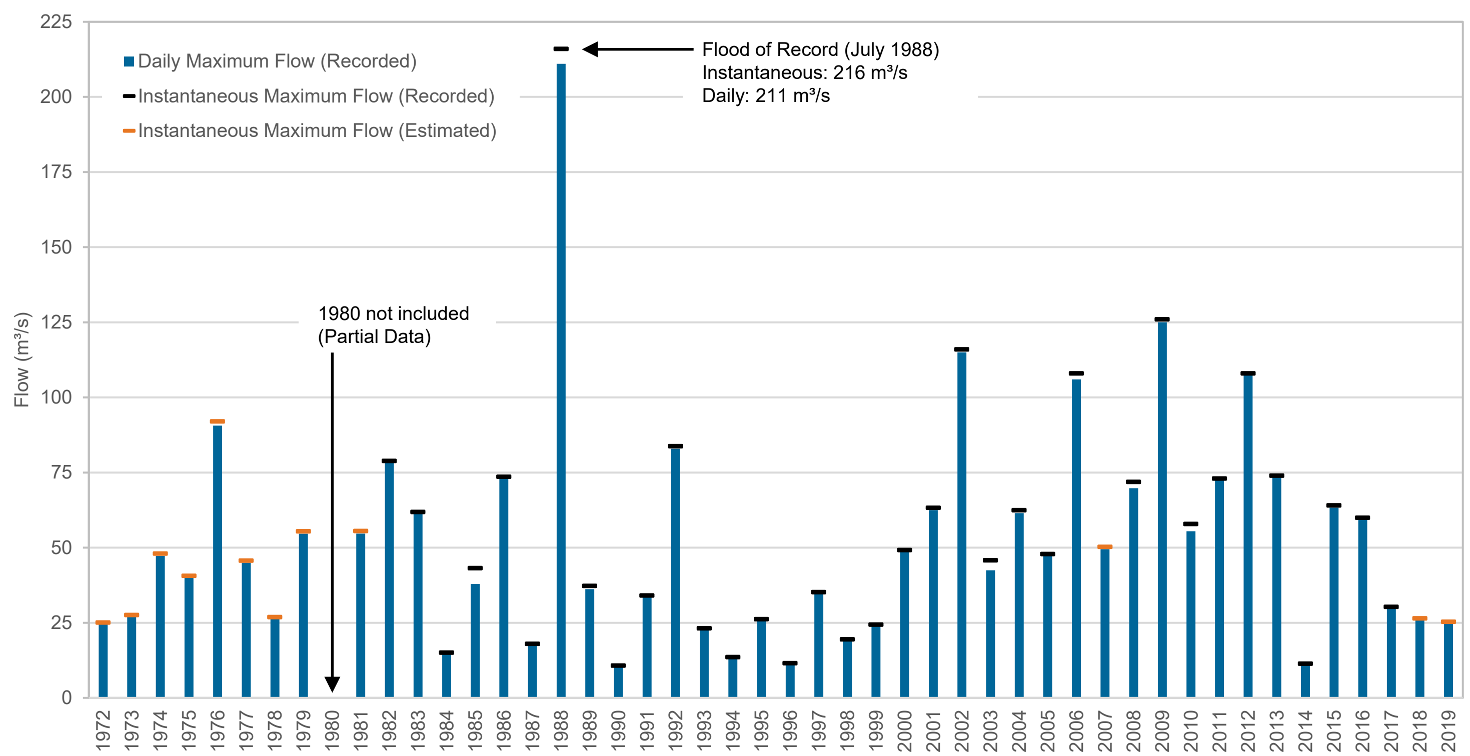
Government of the Northwest Territories and Jacobs
Jean Marie River Bridge Replacement - Highway 1 (Mackenzie Highway)

Historical Aerial Photographs

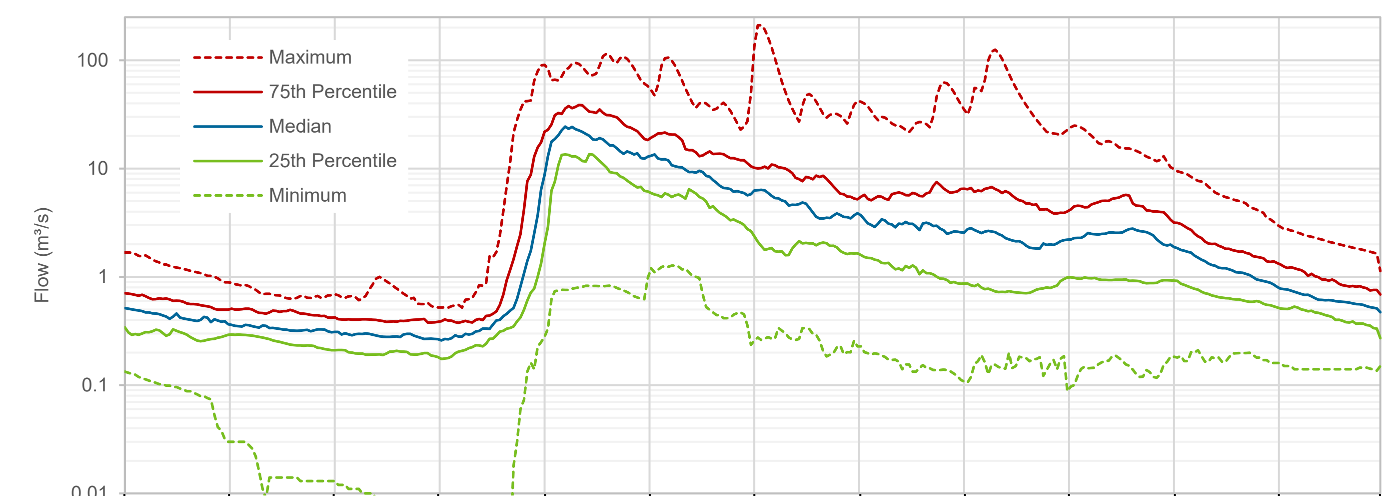
Date: January 2024	Project: 35370-522	Submitter: T. Schaepsmeyer	Reviewer: K. Curtis

Figure 3

Daily Maximum and Instantaneous Maximum Flow History (WSC Station 10FB005)[1-2]



Annual Hydrograph and Monthly Flow Statistics

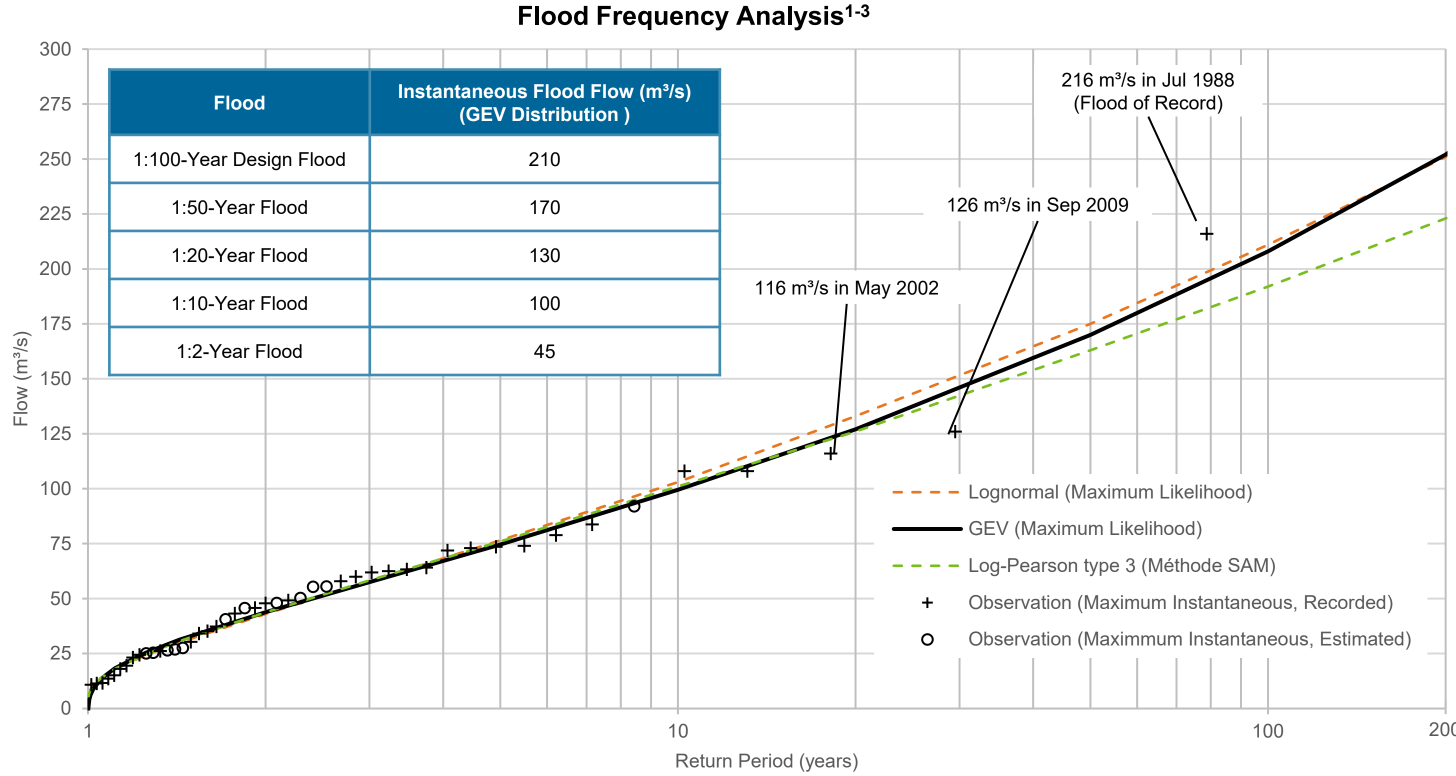


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min. Monthly[4] Flow	0.10	0.02	0.01	0.05	0.77	0.86	0.29	0.17	0.18	0.14	0.19	0.14
Mean Monthly[4] Flow	0.46	0.35	0.30	1.68	22.5	11.8	7.50	5.28	5.16	3.69	1.71	0.77
Max. Monthly[4] Flow	1.26	0.71	0.64	8.42	52.8	45.3	56.5	20.9	47.0	14.3	6.06	2.21

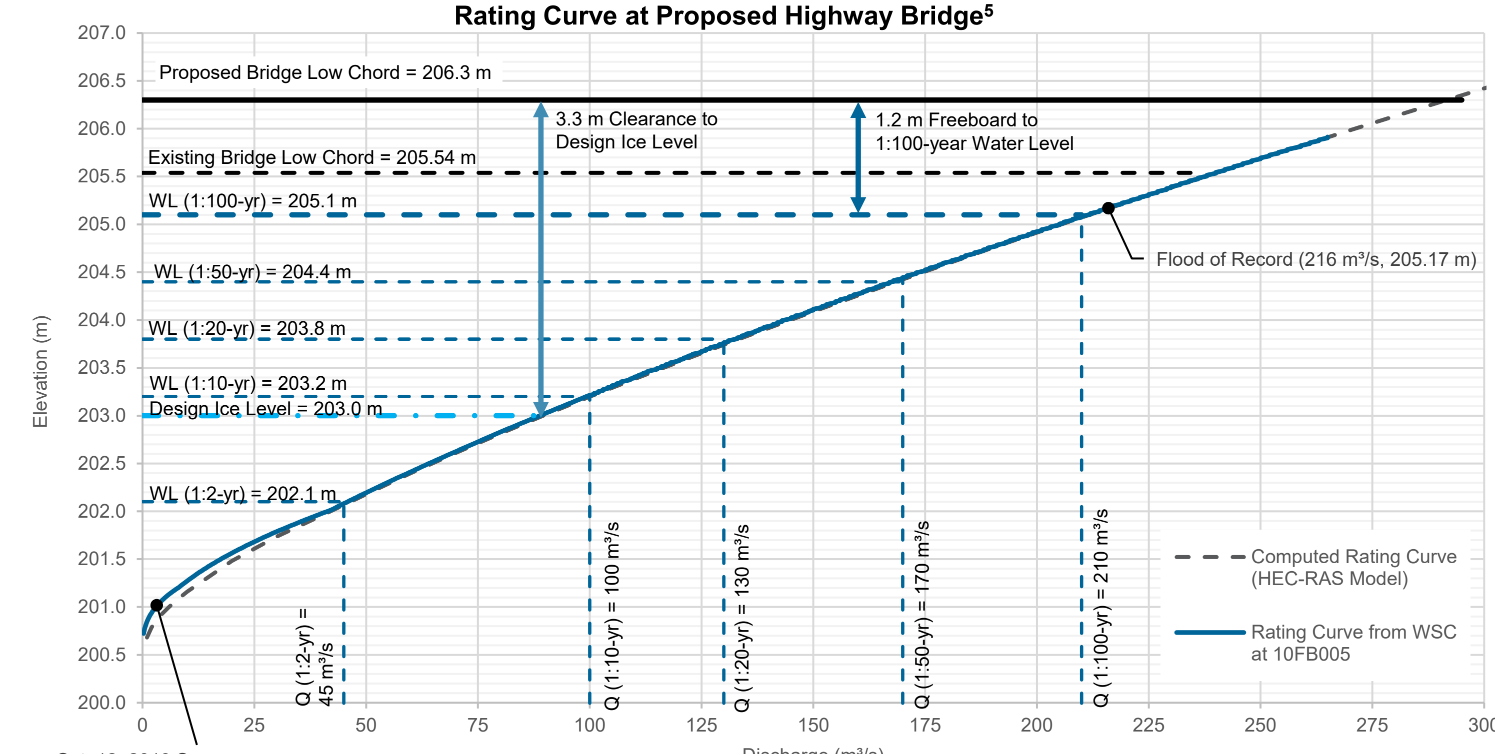
Typical River Ice Season → to Early May ← from Mid-October

Flood Frequency Analysis[1-3]

Flood	Instantaneous Flood Flow (m³/s) (GEV Distribution)
1:100-Year Design Flood	210
1:50-Year Flood	170
1:20-Year Flood	130
1:10-Year Flood	100
1:2-Year Flood	45



Rating Curve at Proposed Highway Bridge[5]



Notes:

1. Flow records are taken from Water Survey of Canada (WSC) hydrometric station 10FB005, located on the Jean Marie River at Highway 1. There are 47 years of daily flow data from 1972 to 1979 and 1981 to 2019, of which there are 35 years of instantaneous flow data.
2. When not available, maximum instantaneous flow is estimated from daily average flow by applying the median ratio of instantaneous to daily flow (1.016) for the floods that had instantaneous flow data. This results in a total maximum instantaneous flow record of 47 years of which 12 years (26%) were estimated.
3. Flood flows are computed from historical flood records and do not include climate change factors.
4. Monthly flow is the average of the daily flows within that month for a given year.
5. Rating curve is for the WSC gauge location, about 40 m upstream of the bridge. There is a negligeable difference between water levels at the WSC gauge and at the bridge due to the flat river grade here (0.1% at the design flood water level). The rating curve computed by the hydraulic model is shown as validation compared to the WSC rating curve.
6. All elevations are relative to the 2013 Canadian Grid Vertical Datum (CVGD2013).
7. Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

"F:\35370\522\2023 Jean Marie Bridge\04 Reporting\Hydrotechnical Report\Figures\Hydrology.pptx"

Matrix Solutions Inc.
A Montrose Environmental Company

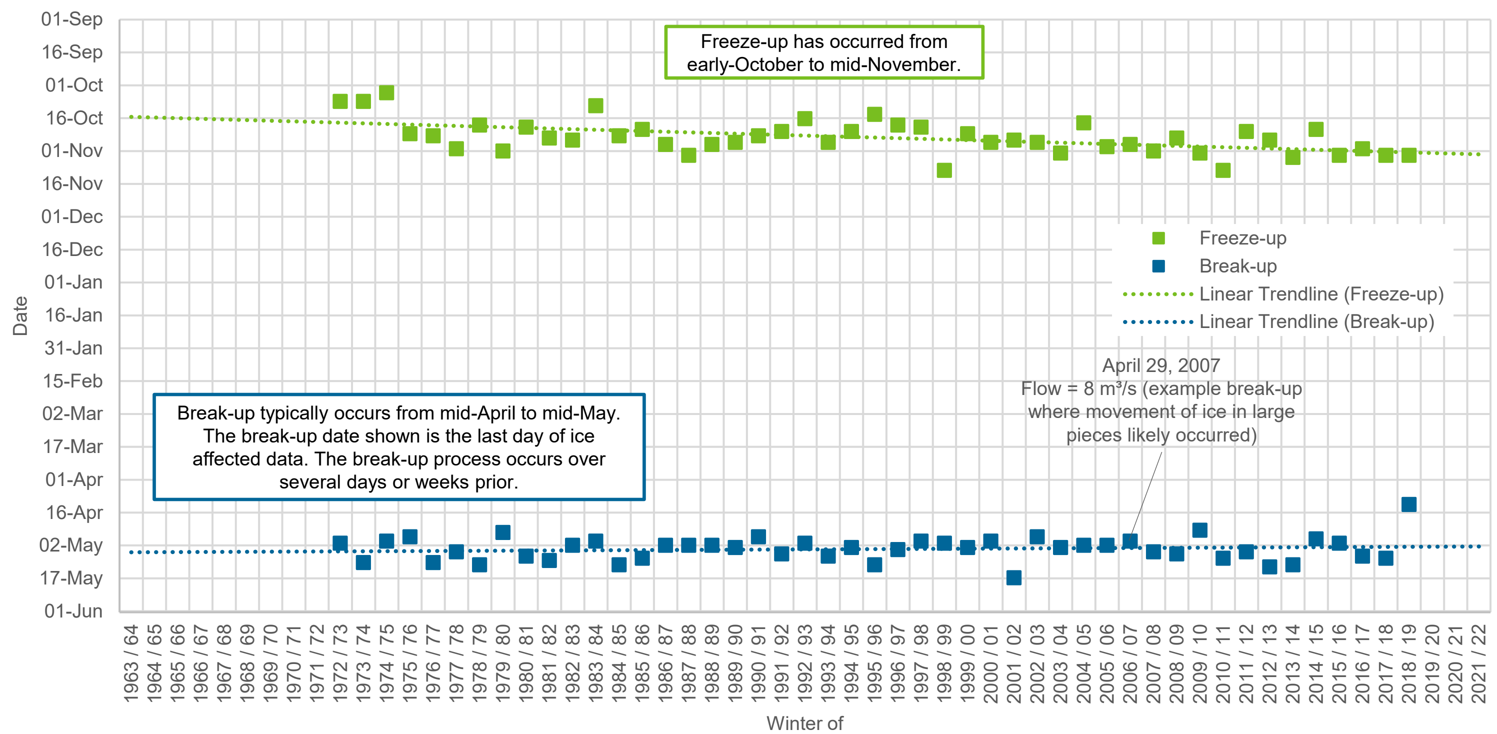
Government of the Northwest Territories and Jacobs
Jean Marie River Bridge Replacement – Highway 1 (Mackenzie Highway)

Hydrologic Analysis and Rating Curve

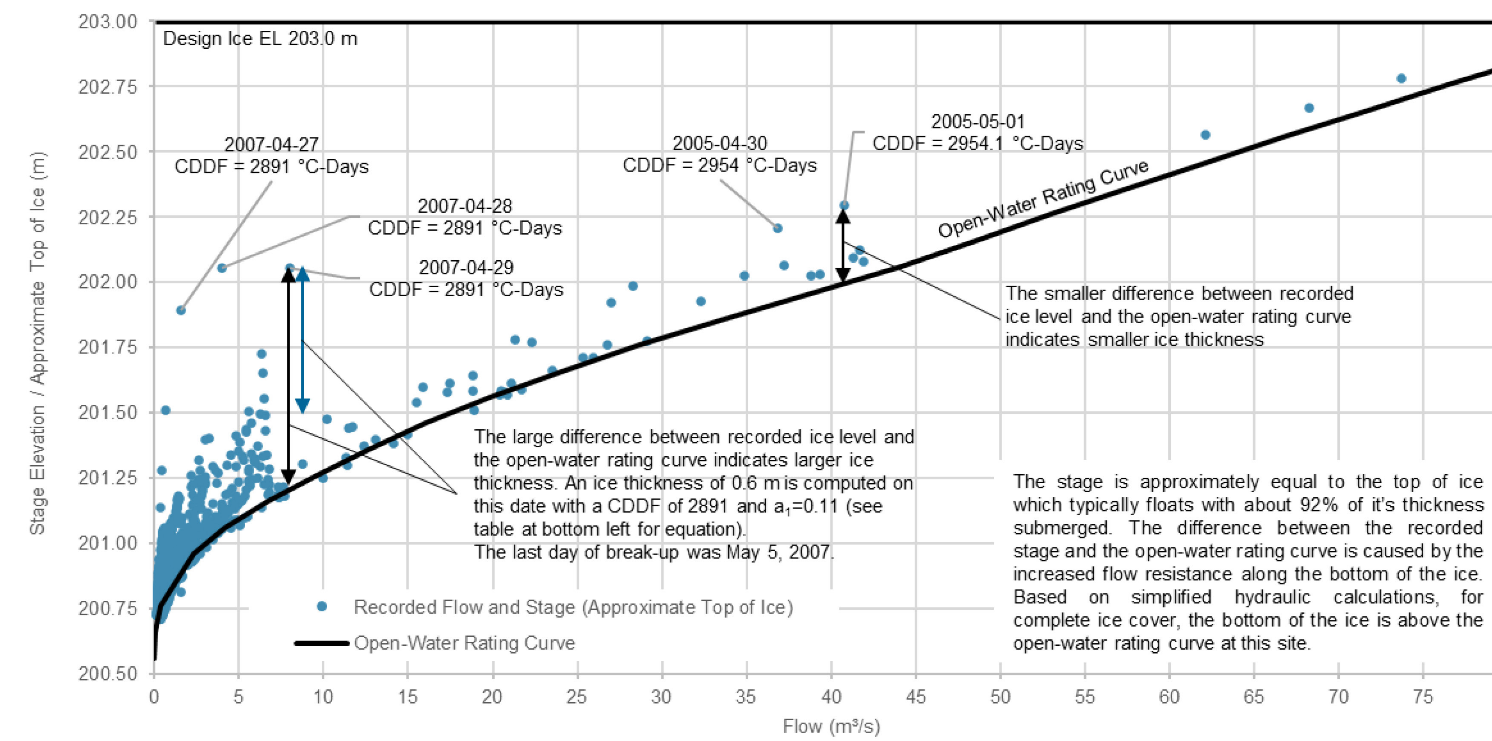
Date:	Project:	Submitter:	Reviewer:
January 2024	35370-522	T. Schaepsmeyer	K. Curtis

Figure 4

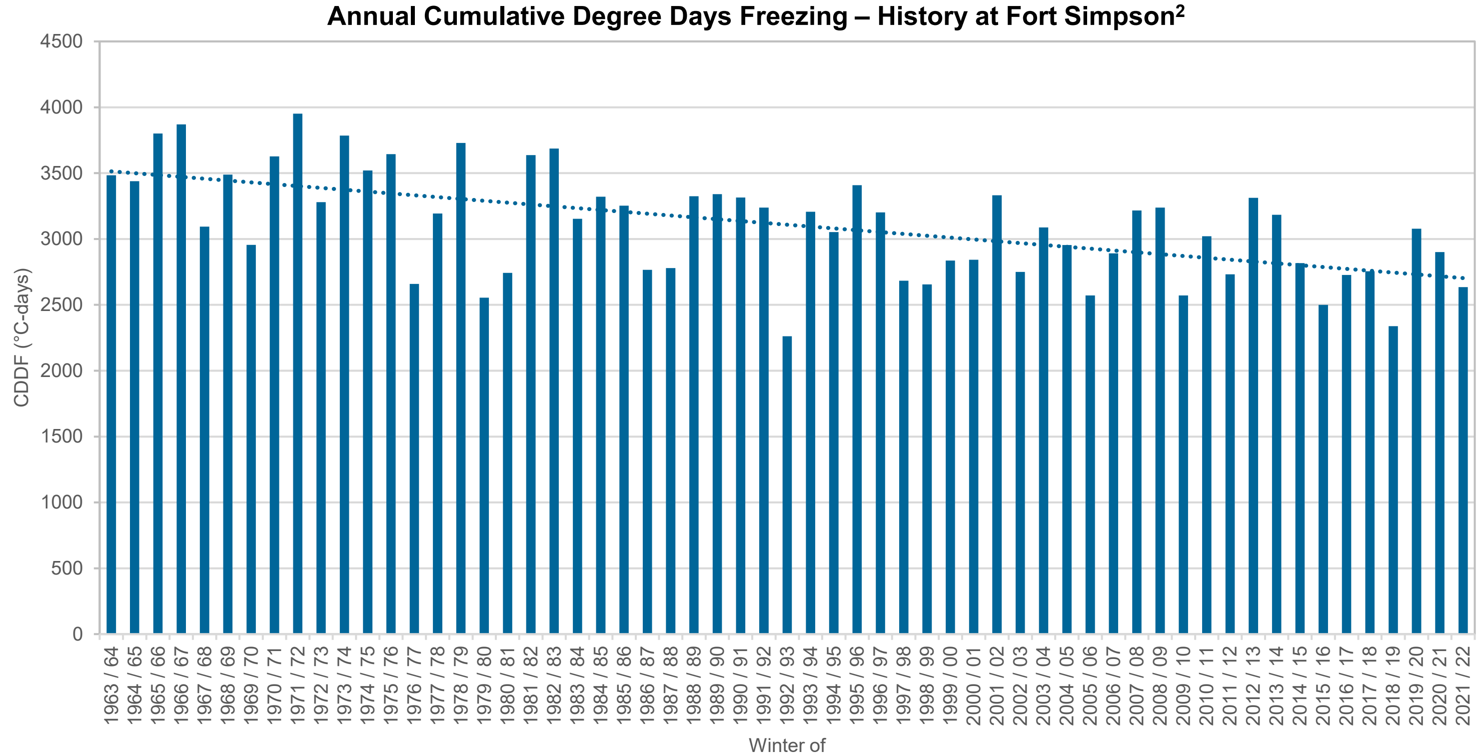
Freeze-up and Break-up History at WSC 10FB005[1]



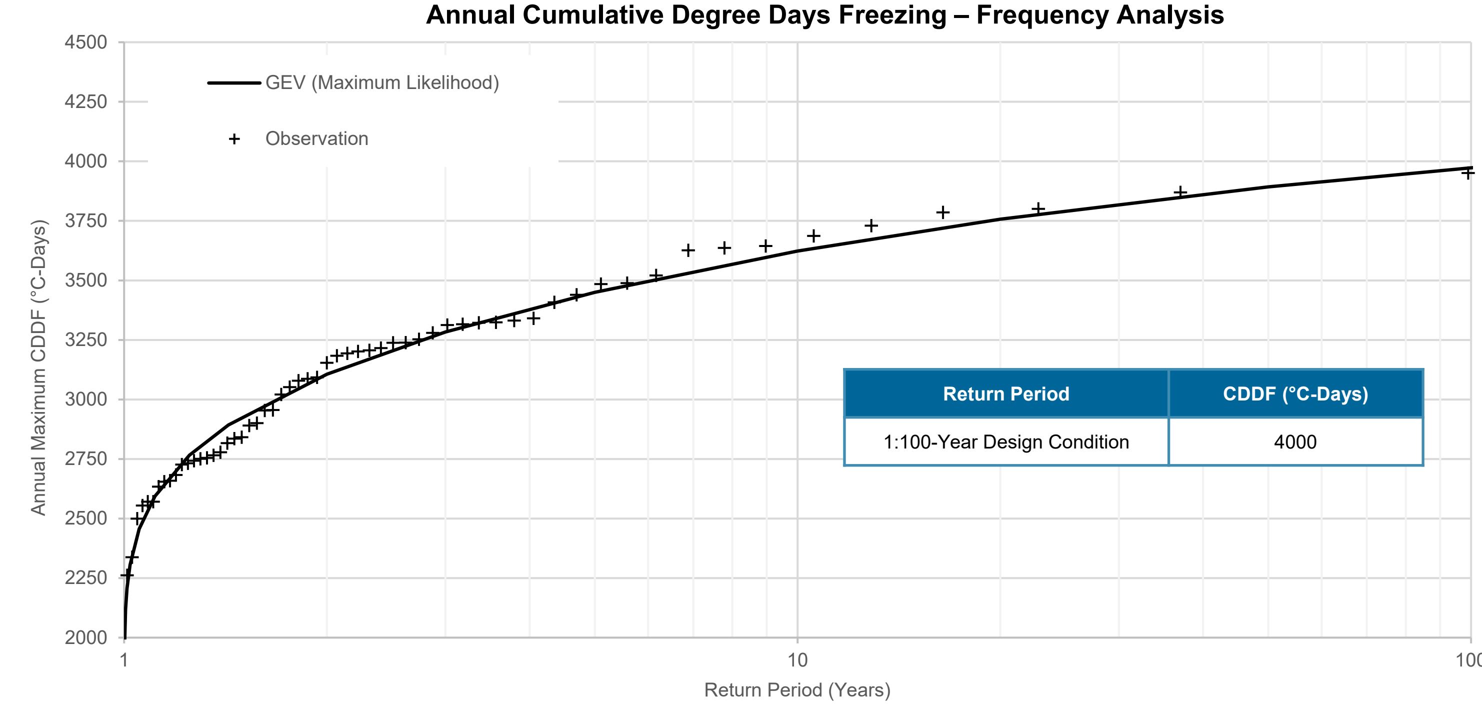
Ice Affected Flow and Stage (2002 to 2019) and Open-Water Rating Curve at WSC 10FB005[1-3]



Annual Cumulative Degree Days Freezing – History at Fort Simpson[2]



Annual Cumulative Degree Days Freezing – Frequency Analysis



Return Period	CDDF (°C-Days)
1:100-Year Design Condition	4000

Ice Thickness Measurements at WSC 10FB005 and 1:100-Year Ice Thickness

Ice Thickness Measurement	Date	CDDF (°C-Days)	Ice Thickness (m)	Computed Value of a_1
1	December 20, 2016	893	0.32	0.011
2	April 14, 2018	2,720	0.54	0.010
3	December 7, 2018	572	0.15	0.006
4	December 4, 2019	464	0.24	0.011
1:100-Year Design Condition*		**4,000**	**0.70**	**0.011**

Note: Ice thickness is computed as a_1*(CDDF)$^{0.5}$, with a_1 = 0.011 calibrated from WSC ice thickness measurements
For comparison: the computed ice thickness for CDDF = 3,500 °C-days (the maximum CDDF since 1983) is 0.65 m

Notes:

1. Flow, water level, and ice records are taken from Water Survey of Canada (WSC) hydrometric station 10FB005, located on the Jean Marie River at Highway 1. There are 18 winters of stage measurements and 4 ice thickness measurements.
2. Climate data from Environment Canada weather station "Fort Simpson A", active 1963 to 2014 (Climate ID 2202101) and 2014 to 2023 (Climate ID 2202103).
3. All elevations are relative to the 2013 Canadian Grid Vertical Datum (CVGD2013).

Matrix Solutions Inc.
A Montrose Environmental Company

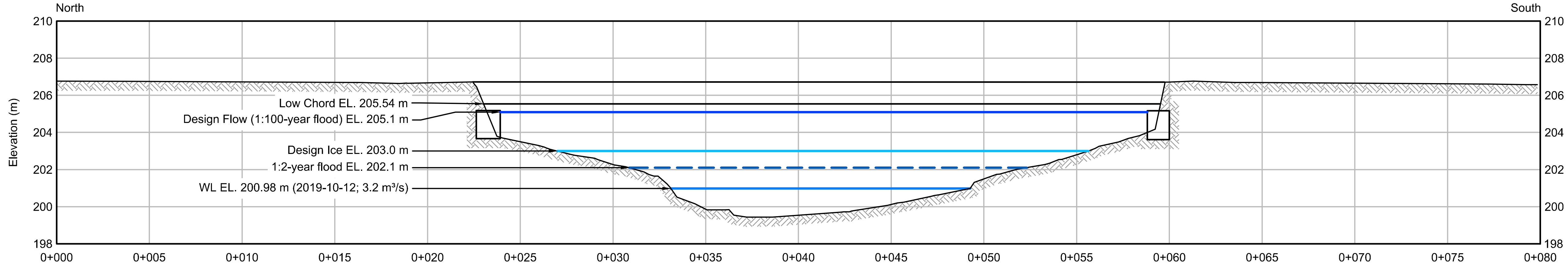
Government of the Northwest Territories and Jacobs
Jean Marie River Bridge Replacement – Highway 1 (Mackenzie Highway)

River Ice Analysis

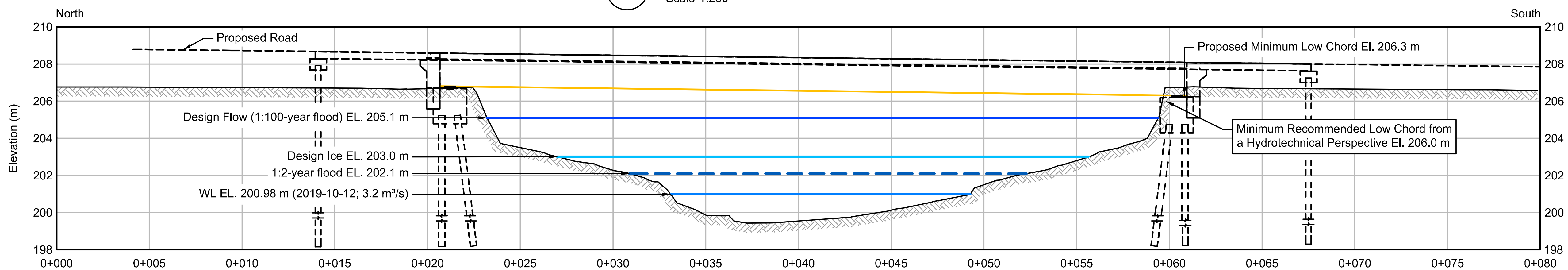
Date:	Project:	Submitter:	Reviewer:
January 2024	35370-522	T. Schaepsmeyer	K. Curtis

Figure 5

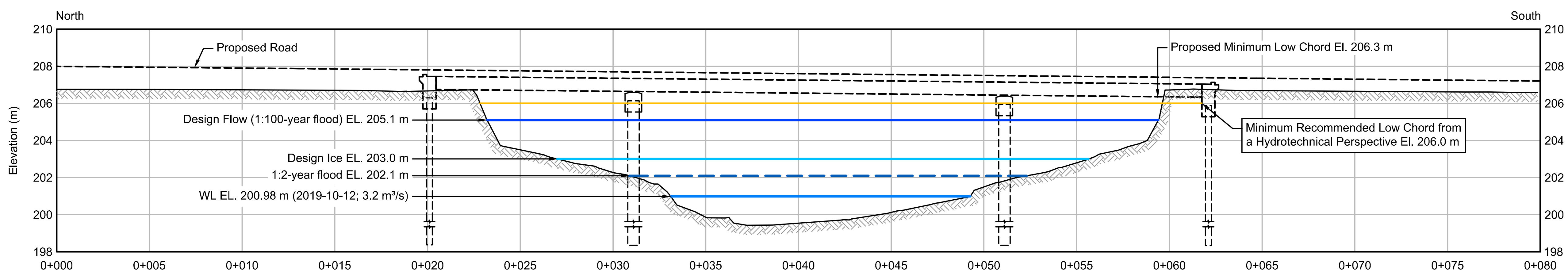
"F:\35370\522\2023 Jean Marie Bridge\04 Reporting\Hydrotechnical Report\Figures\Ice Analysis.pptx"



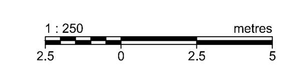
Section - Existing Jean Marie River Bridge
Scale 1:250



Section - Proposed Jean Marie River Single Span Bridge
Scale 1:250



Section - Proposed Jean Marie River Three Span Bridge
Scale 1:250



Notes:
1. Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.
2. Elevations are in CGVD2013 Vertical Datum.

Horizontal Clearance	
Existing Bridge	35 m clear-span
Proposed Single Span Option	37.4 m clear-span
Proposed 3 Span Option	20 m between the piers

Vertical Clearance				
Flow Condition	**Water Level (m)**	**Minimum Clearance (m)**		
		Existing Bridge	**Proposed Single Span Option**	**Proposed 3 Span Option**
Design Flow (1:100-year flood)	205.1	0.44	1.2	1.2
1:50-Year	204.4	1.14	1.9	1.9
1:20-Year	203.8	1.74	2.5	2.5
1:2-Year	202.1	3.44	4.2	4.2

References:
1. Existing bridge as per 1968 Construction Drawings. Government of Northwest Territories.
2. Proposed three-span bridge option as per Jacobs Bridge Replacement Structure Alternatives and Design Selection Report Selection. March 2023.
3. Proposed single-span bridge option as per Jacobs 80% Draft Drawings. October 2023.
4. 2019-10-12 water level and flow are from Water Survey of Canada Real-Time data for Jean Marie River.

Matrix Solutions Inc.
A Montrose Environmental Company

Government of the Northwest Territories and Jacobs
Jean Marie River Bridge Replacement - Highway 1 (Mackenzie Highway)

Existing and Proposed Bridges Cross-sections and Clearances

Date: January 2024	Project: 35370-522	Submitter: T. Schaepsmeyer	Reviewer: K. Curtis

Figure 6

APPENDIX A
Temporary Bridge Design Criteria Memorandum

Matrix Solutions Inc.
A Montrose Environmental Company

MEMORANDUM

TO: Azita Azarnejad, Jacobs

FROM: Thomas Schaepsmeyer, M.Eng., P.Eng. and Katy Curtis, P.Eng., Matrix Solutions Inc.

SUBJECT: Jean Marie River Temporary Bridge – Design Criteria

DATE: April 2, 2024

VERSION: 2.0

1 INTRODUCTION

A temporary bridge immediately upstream of the permanent bridge is proposed by Jacobs to allow traffic to cross the river during construction. The B.C. Ministry of Transportation and Infrastructure *Supplement to CHBDC S6-19* (B.C. MoTI 2022) recommends that temporary bridges be designed for the maximum instantaneous 1:10-year flood for bridges in place for 2 years or less.

2 RECOMMENDED HYDROTECHNICAL DESIGN

The recommended hydrotechnical design criteria for the temporary bridge are provided in Table 1.

TABLE 1 Recommended Hydrotechnical Design Criteria for the Temporary Bridge

Parameter	Value	Comment/Rationale
Flood return period	1:10-year	As per BC MoTI Supplement to the CHBDC
Design flow[1,2]	100 m^3/s	As per analysis of 47 years of flow data
Design water level[2]	203.2 m	As per WSC Rating Curve
Minimum freeboard[2,3]	0.4 m	Matching the freeboard of the existing bridge, which had 0.4 m clearance during the 1988 flood of record
Minimum bridge low chord elevation	203.6 m	
Minimum recommended span[4]	25 m	Minimum 25 m span to for practical construction

Notes:

1. The design flow is the instantaneous peak flow.
2. The 1:10-year design flood and water level do not include climate change. The proposed temporary bridge is not expected to cause a rise in water levels.
3. Temporary bridge design to be prepared by contractor.
4. All temporary bridge works will be outside of the 1:2-Year WL.

VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V1.0	21-Jul 2023	Final	35370-522 Memo 2023-07-21 final V1.0.docx	Issued to client as Final
V2.0	02-April-2024	Final	35370-522 Memo 2024-04-02 final V2.0.docx	Issued to client as Final

REFERENCE

British Columbia Ministry of Transportation and Infrastructure (B.C. MoTI). 2022. *Bridge Standards and Procedures Manual: Volume 1: Supplement to CHBDC S6:19*. July 2022. https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/bridge/volume-1/2022/volume-1.pdf