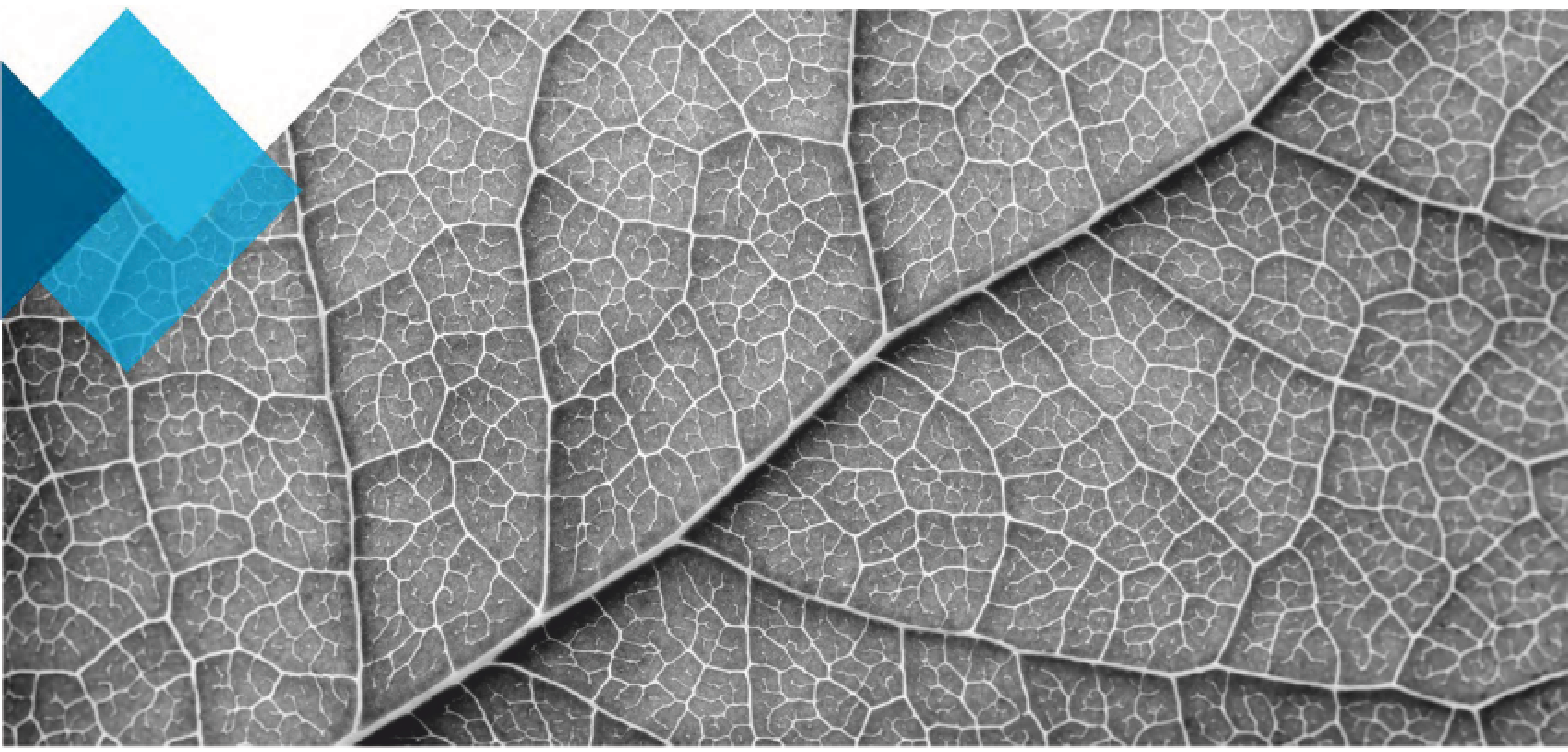
2020 Inundation Study and Dam Safety Review Final Report

Bear River Control Structure

City of Grande Prairie



Environment & Geoscience

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Executive Summary

The City of Grande Prairie (the City) retained SNC-Lavalin Inc. (SNC-Lavalin) to carry out an independent Dam Safety Review (DSR) for the Bear River Control Structure. In addition to the DSR, the City requested that SNC-Lavalin complete the following during this project:

› Conduct a flood inundation study to support the incremental consequence classification of the facility;

› Develop an Operation, Maintenance, and Surveillance (OMS) Manual for the facility, along with preparing an Annual Inspection form to allow for routine inspection by the City staff; and

› Develop an Emergency Preparedness Plan and an Emergency Response Plan and Flood Action Plan.

The Bear River Control Structure is located in SW-26-71-6-W6 in the City of Grande Prairie, Alberta. It was originally built in 1948, reconstructed in 1975-76, and is operated and maintained by the City. The dam and control structure on Bear River form the Bear River Reservoir. Release from the reservoir is controlled by a gated spillway consisting of a cast-in-place reinforced concrete chute with two gated bays of radial gates which are operated manually to manage spring floods and winter recreation. The dam is currently licensed for recreation and erosion control purposes.

The dam is an approximately 5 m high earth fill dam approximately 170 m long with a crest elevation 655 m. The upstream slopes of the dam are approximately 3.5H:1V and the downstream slopes are approximately 7H:1V. The concrete spillway chute is 15 m long with a drop of 6.4 m.

This report documents the details of the results of this DSR with the main findings summarized below:

› The Bear River Control Structure is in satisfactory condition and there are no critical dam safety deficiencies that will require immediate action;

› Based on the site inspection, document review, and dam safety assessment completed, the dam and the spillway are safe and stable under normal operating conditions;

› The incremental consequence classification assessment for Bear River for both fair weather and flood induced conditions resulted in a consequence classification of "Significant";

› The Inflow Design Flood (IDF) for the Bear River Dam is recommended to be the 500-year flood event;

› While the spillway capacity is sufficient to allow for the routing of the IDF, the available freeboard (0.35 m) is insufficient when considering the wave action. Options to increase the available freeboard, such as raising the top of the structure or providing a flashboard barrier for wave action and runup, should be studied;

› The structural analyses conclude that the spillway concrete structure meets all the stability criteria set forth in the Canadian Dam Association (CDA) Guidelines;

› The middle trunnion concrete block has sufficient strength to resisting trunnion force from the new IDF flood level of 654.65 m; and

- Considering that the gates are maintained partially open as part of normal winter operation of the Bear River Control Structure, the middle trunnion concrete block has sufficient strength to resist trunnion force resulting from the ice load estimated using the CEATI Ice Loading Model on the partially open gates. Site specific measurements are recommended to confirm the ice loads considered in the present assessment. It is anticipated that any change in gate operation during winter would also consider the corresponding change in trunnion load and safety of the trunnion block should be reviewed.

Based on the current regulatory requirements and the results of the DSR for the Bear River Dam and Control Structure, the next DSR should be carried out in 2030.

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Abbreviations and Acronyms

ADCSD ....Alberta Dam and Canal Safety Directive
AEP ....Annual Exceedance Probability
CDA..................Canadian Dam Association
CEATI ....Center for Energy Advancement through Technical Innovation
the City ....City of Grande Prairie
DEP ....Digital Elevation Model
DSG..................Dam Safety Guidelines
DSMS ....Dam Safety Management System
DSR..................Dam Safety Review
EDGM...............Earthquake Design Ground Motion
EPP ....Emergency Preparedness Plan
ERP ....Emergency Response Plan
FSL...................Full Supply Level
FOS ....Factor of Safety
GOA ....Government of Alberta
HEC-RAS ....Hydrologic Engineering Center's River Analysis System
ICC ....Incremental Consequence Classification
IDF....................Inflow design flood
km.....................kilometre
LiDAR ....Light Detection and Ranging
LOL...................Loss of Life
m ....metre
m^3/s ....cubic metres per second
OMS ....Operations, Maintenance, and Surveillance Manual
PAR ....population at risk
PGA..................peak ground acceleration
PMF..................probable maximum flood
PMP..................Probable Maximum Precipitation
RFP ....Request for Proposal
QPOs................Quantitative Performance Objectives
RAP ....Restricted Activity Period
SD ....Standard Deviation
SF ....Safety Factors
SNC-Lavalin ....SNC-Lavalin Inc.
WSC ....Water Survey Canada
1D ....One Dimensional

1 Introduction

1.1 General

The City of Grande Prairie (the City) retained SNC-Lavalin Inc. (SNC-Lavalin) to carry out an independent Dam Safety Review (DSR) for the Bear River Control Structure. SNC-Lavalin submitted a detailed proposal for this project dated June 25, 2020 in response to a Request for Proposal (RFP) 2020-54 dated June 1, 2020. The project was awarded to SNC-Lavalin on July 7, 2020 and the project kickoff meeting was held on July 22, 2020.

1.2 Scope of Work

The overarching objective of the project was to complete a DSR for the Bear River Dam and Control Structure. The DSR is usually a part of the dam safety management system with the overarching goal of protecting people, property, and the environment from harmful effects of failure of the dam, reservoir, or operations. As such, the objective of the 2020 DSR is to:

- Evaluate the safety of the dam and associated structures.
- Confirm the dam is in compliance with regulatory requirements such as *Alberta Water Act,* Water (Ministerial) Regulation – Part 6, and best practices (Canadian Dam Association [CDA]. 2013. Dam Safety Guidelines, 2007. Revised 2013) and accompanying Bulletins.
- Identify and prioritize known and any new deficiencies and make recommendations to mitigate these deficiencies.
- Identify any data gaps and/or study requirements for safe operations of the dam.
- Address the key issues identified by the City in support of the DSR.
- Carry out the Scope of Work as outlined in the RFP Appendix D – RFP Particulars.

The 2013 DSR (Golder 2014) was carried out in conformance with the CDA Dam Safety Guidelines of 2007. Based on a qualitative dam consequence assessment of the DSR, the dam classification was upgraded from the previous “Low” to “Significant”. The 2013 DSR proposed recommendations and the City outlined the key issues that need to be addressed in this project.

- **Operation, Maintenance, and Surveillance (OMS) Manual and Annual Inspection Form:** Prior to this project, there was no OMS Manual for the Bear River Radial Gates. The City requested that SNC-Lavalin develop an OMS Manual, along with preparing an Annual Inspection form to allow for routine inspection by the City staff.
- **Emergency Management Plan and Signage:** The City requested that SNC-Lavalin create both an Emergency Preparedness Plan and an Emergency Response Plan and Flood Action Plan. The existing signage around the control structure was known to be inadequate or non-existent. To rectify this, SNC-Lavalin developed a signage document for the City recommending adequate signage at the correct places.

- **Flood Inundation Study:** The 2013 DSR qualitatively assigned the consequence classification of the dam based on a qualitative assessment. A flood inundation study which supports the incremental consequence classification was conducted during this project.

- **Bypass Infrastructure:** The current spillway and gates have the capacity to pass the 100-Year flow. Through updating the classification of the dam and determining the Inflow Design Flood (IDF), SNC-Lavalin identified no bypass is required for Bear River Dam.

- **Freeboard of the Reservoir:** SNC-Lavalin calculated and graphically demonstrated the existing available freeboard for the reservoir during the IDF.

- **Ice Loading on the Spillway Concrete Structures and Gates:** SNC-Lavalin's structural engineers calculated the ice loading on the spillway concrete structures and gates during winter ice condition and provided recommendations for addressing any concerns.

1.3 Project Team

The SNC-Lavalin DSR team that completed this project included:

- Alistair James, P.Eng., Principal Geotechnical Engineer, Project Manager and Geotechnical Lead;

- Daniel Damov, M.A.Sc., Eng., Senior Hydrology/Hydraulics Engineer, Hydrotechnical Lead;

- Arif Kartawidjaja, P.Eng., Senior Structural Engineer, Structural Lead;

- Maryam Nasseri, P.Eng., Senior Mechanical Engineer, Mechanical & Electrical (M&E) Lead;

- Chris Duncan, P.Eng., Geotechnical Engineer, overall engineering coordination and project manager delegate; and

- Haimanot Yadete, P.Eng., Senior Hydrotechnical Engineer.

1.4 Previous Dam Safety Reviews

Previous DSRs completed for the Bear River Control Structure are listed below:

- 2013 DSR, completed by Golder Associates (Golder 2014).

2 Project Description

2.1 Site Location and Layout

The Bear River Control Structure is located in SW-26-71-6-W6 in the City of Grande Prairie, Alberta. It was originally built in 1948, reconstructed in 1975-76, and is operated and maintained by the City. The dam and control structure on Bear River form the Bear River Reservoir. Release from the reservoir is controlled by a gated spillway consisting of a cast-in-place reinforced concrete chute with two gated bays equipped with radial gates which are operated manually to manage spring floods and winter recreation. The gates were replaced in 2008. The dam is currently licensed for recreation and downstream erosion control purposes. A site location plan is shown on Drawing 1 and a site layout plan is shown on Drawing 2.

2.2 Summary of Project Data

Key facility information for the Bear River Reservoir and Control Structure are listed in **Table 2.1**.

Table 2.1 Summary of the Key Facility Information for Bear River

Parameter	Value	Note
Reservoir		
Full Supply Level (FSL)	652.58 m	From design drawing
Total Capacity at FSL	162 dam^3	Calculated
Water Surface Area at FSL	15.6 ha	Calculated
Drainage Area	1,566 km^2	From previous study
100 Year Flood Peak	120 m^3	Calculated
Dam		
Dam Crest Elevation	655 m	From survey
Embankment Height	4.75 m	Calculated
Crest Length	170 m	From survey
Crest Width	4 m	From survey
Upstream Slope	3.5:1V	From design drawing
Downstream Slope	7H:1V	From design drawing
Freeboard at FSL	2.42 m	Calculated
Spillway		
Number of Gates	2	From design drawing
Dimensions of Radial Gates (height x width)	3.89 m x 5.5 m	From design drawing
Length of Chute	15 m	From design drawing
Top of Spillway Elevation	650.44 m	From design drawing
Spillway Sill Elevation	644.04 m	From design drawing
Drop Height of Chute	6.4 m	From design drawing
Spillway Capacity at FSL	52.6 m^3/s	Calculated

3 Status of Recommendations from 2013 DSR

Recommendations provided for Bear River in the 2013 DSR (Golder 2014) and their status as of December 2020 are listed in **Table 3.1**.

Table 3.1 Summary of Recommendations in the 2013 DSR (Golder 2014)

2013 DSR Recommendation	Status as of December 2020
A dam breach inundation study should be carried out to estimate consequences related to potential loss of life and infrastructure damage.	Completed as part of the 2020 DSR
The Dam Class and appropriate Inflow Design Flood should be confirmed as part of the dam breach inundation study.	Completed as part of the 2020 DSR
The available freeboard during the IDF event should be calculated, and additional flood passage options, such as emergency spillway or fuse plug, should be investigated if the available freeboard is found to be inadequate.	Completed as part of the 2020 DSR
An EPP, ERP, and OMS Manual for the project should be developed to provide dam operators and the City with information to be able to identify emergency conditions, take appropriate mitigation measures, and guide emergency response.	Completed as part of the 2020 DSR
An inspection of the concrete spillway chute should be scheduled when the reservoir level is below 650.75 m and the stilling basing can be de-watered.	Completed as part of the 2020 DSR
The ice loading on gates during complete river freeze-up should be determined and checked against design ice load.	Completed as part of the 2020 DSR
The gate operations should be reviewed to ensure that sufficient flow can pass over the top of the gates without overtopping the dam, should the gates not be operational in spring.	Completed as part of the 2020 DSR
The operator gate hand wheels should be removed or locked out.	Outstanding
Warning signs should be posted around the structure. Orange warning buoys should be attached to the cable across the approach channel to provide more visibility to the hazardous conditions closer to the spillway.	Outstanding

4 Site Inspection

4.1 General

Prior to the site inspection, SNC-Lavalin submitted an application to Alberta Environment and Parks (AEP) for approval to de-water the dam spillway in order to conduct a full inspection of the spillway, as well as a request for review to the Department of Fisheries and Oceans (DFO). In September 2020, SNC-Lavalin was notified by AEP that the application would not be processed in time to complete the full inspection before winter. It was determined that a partial site inspection would be completed in 2020, with the full spillway inspection put on hold until spring/summer 2021.

SNC-Lavalin completed a detailed inspection of the dam and partial inspection of the spillway on October 15, 2020. SNC-Lavalin's DSR inspection team was comprised of the following individuals:

- Alistair James, P.Eng., Principal Geotechnical Engineer and Project Manager;
- Chris Duncan, P.Eng., Geotechnical Engineer;
- Haimanot Yadete, P.Eng., Hydrotechnical Engineer; and
- Laura Jones, E.I.T., Mechanical Engineer-in-Training.

After completing the permitting process, SNC-Lavalin arranged for a spillway pump-around to maintain adequate downstream flow in Bear River so the spillway gates could be closed, and the basin dewatered for inspection.

The full inspection of the spillway took place on June 8, 2021, and was conducted by Alistair James and Chris Duncan of SNC-Lavalin.

During both inspections, Richard Sali and Mike Harvard of the City escorted and provided responses to queries raised by the inspection team.

SNC-Lavalin personnel took detailed notes of their visual observations for geotechnical, hydrotechnical, structural, mechanical, and electrical safety management aspects of the dam, spillway, reservoir, and shorelines. The DSR Team documented their site inspection notes in the site inspection report which was submitted to the City for review on November 19, 2020. The site inspection report was revised as per the City's review comments and is provided in Appendix I. A compilation of photographs taken during the site inspection by the SNC-Lavalin DSR Team is also provided in Appendix I.

This section summarizes the outcome of the visual inspections, project-specific condition inspections, and interviews of the City dam safety staff during the site inspection.

4.2 Visual Inspection

4.2.1 Main Dam

The visual inspection of the main dam and abutments looked for evidence of possible concerns such as:

- depressions, sinkholes, or signs of settlement;
- desiccation or frost heave cracking;
- bulging in the slopes;
- evidence of seepage;
- indications of movement such as tension crack, rotation, heave, or subsidence; and
- signs of surface erosion and/or degradation of slope protection.

Aside from some minor depressions located along the former spillway location, no signs of any of the concerns listed above were evident during the site inspection and the dam crest, downstream and upstream slopes, and the abutments were in good condition.

The upstream slope of the dam is protected by riprap above and below the water surface, consisting of well-graded rounded cobbles and boulders between 100 mm and 300 mm in diameter. The riprap is in fair condition, through it is overgrown with vegetation in parts and is starting to show signs of weathering. Above the riprap, the upstream slope is vegetated with a mixture of trees, native grasses, bushes, and shrubs.

The downstream slope of the dam is vegetated with established park grasses and shows no indication of instability. No evidence of seepage daylighting on the face of the dam was evident. Small depressions were observed on the downstream slope on the north side of the dam. From historical photographs supplied by the City, it appears that these depressions are located where the original spillway was constructed.

Maintenance and monitoring issues noted during the inspection of the dam are summarized below:

- There is a bush growing within the fenced access at the top of the spillway that prevents immediate access to the eastern gate and its mechanism. The bush should be removed to prevent obstruction (noted to have been removed during 2021 spillway inspection).
- Depressions were observed on the north side of the downstream slope of the dam. This area should be monitored for any further changes, water seepage, or further movement.
- There are a number of trees and bushes growing on the upstream slopes, crest, and downstream slopes of the dam. The trees (particularly the large deciduous trees) and bushes on the dam should be removed at some point in the next few years. **Figure 4.1** shows the areas where the trees and bushes should be removed. All trees and bushes should be cleared from the area highlighted in orange. Trees and bushes with root structures that penetrate less than 1 m into the dam are permitted in the area highlighted in yellow, with coverage of less than 5% of the total area recommended.

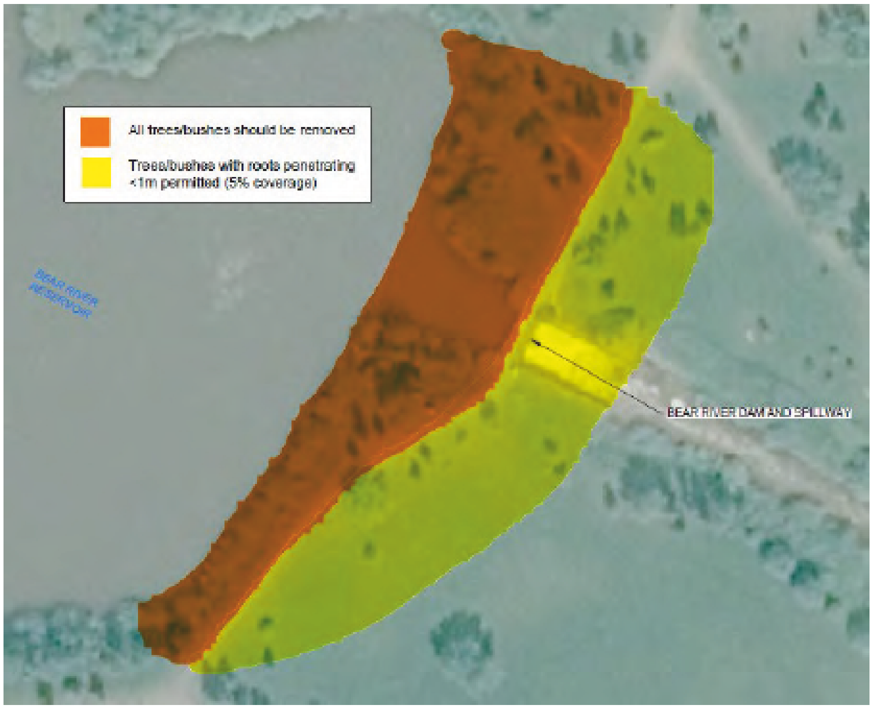


Figure 4.1 Locations for Tree/Bush Removal

4.2.2 Reservoir, Shorelines, and Inlet Channel

The shorelines of the reservoir and spillway approach channel are all in good condition. The riprap protecting the shorelines is in satisfactory condition with minor vegetation growth and minor weathering.

Maintenance issues noted during the inspection of the reservoir shorelines are summarized below:

- The spillway approach boom was not in place during the inspection. The boom should be reinstated and maintained to remove debris following storm events. Temporary removal of the boom to accommodate maintenance, such as removal of debris, is acceptable. However, the boom should be reinstated at the earliest opportunity after the maintenance.
- The 2018 bathymetry data of the reservoir shows that the reservoir completely lost its dead storage due to sediment deposition and almost acts as a river. Monitoring of sediment deposit will be required to assess the impact on the loss of live storage of the reservoir. Dredging of sediment is advisable to increase reservoir storage capacity, especially at freshet, but would not provide enhanced protection to the dam structure (reduced risk) as the reservoir levels are controlled by the spillway.
- The upstream slope and approach riprap are in fair condition but may not meet current design standards. It is also overgrown in parts. Although vegetation is providing protection, there is a risk of the loss of protection should the vegetation by destroyed (e.g., by disease or fire).

4.2.3 Spillway

The spillway consists of a two-bay cast-in-place concrete retaining structure. The concrete structures of the spillway which include the headworks, spillway slab, spillway chute, and the stilling basin were visually inspected to assess the condition of the concrete, conditions of joints, cracks, movement, or any other signs of deterioration. Overall, the concrete was in fair condition at the time of the site inspection.

The spillway slab concrete was in satisfactory condition with moderate roughness and no major cracking. Slab joints were in satisfactory condition.

The chute walls were in satisfactory condition with no major deterioration or cracking. Most of the chute wall joints are in satisfactory condition. There are significant cracks in the second joint down the spillway on both the south and north sides of the spillway that should be repaired as the rebar is exposed.

The stilling basin concrete and joints are in satisfactory condition with moderate roughness and no major cracking. A few of the energy dissipation baffles have corners/edges that are chipped, but no exposed rebar.

The concrete strength was tested using a Humboldt H-2987H Concrete Rebound Hammer. Test results were highly variable both due to the accumulation of organic matter on the concrete surface below the waterline, and due to moderate surface roughness and weathering. The tests indicated that the strength of the spillway walls was between 25 MPa and 40 MPa. Some readings in the range of 20 MPa were obtained below the water line in the spillway, but it is our assessment that those readings were impacted by surface wetness and the accumulation of organic matter. The range of 25 MPa to 40 MPa represents the average of readings obtained on the dry concrete surface, which is in line with the design value of 30 MPa.

The channel riprap downstream of the stilling basin is intact and is in place adjacent to the stilling basin, with no visible undermining of the basin.

4.2.4 Mechanical and Electrical

The spillway gates, hoists, and electrical systems were all inspected. Operation of both gates was tested and opening and closing of both gates was noted to be smooth and without noise or vibration.

Maintenance issues noted during the inspection of the mechanical and electrical works are summarized below:

- There are bushes and tree branches accumulated on top of the gates and horizontal girders. A tree branch was caught on the south arm of the south gate as well. Minor damages have been shown on the J seal from the debris accumulating on top of the gates. The affected areas on the gates should be cleared from branches and debris.
- Debris was seen wedged or hanged between the cables and skin plate. The condition of the connection points between the cables and skin plates at the bottom of the gates shall be checked regularly for damage or corrosion and any debris or branches shall be removed.

- Corrosion is forming on the gate hoisting equipment. Cable drums and pulleys were showing light corrosion at the contact points with the cables. The block bearings, couplings, and drive shafts show minor corrosion. The equipment should be painted to prevent corrosion.

- The hoist hand wheels do not have any lock-out devices. It is recommended that the hand hoist wheels be removed or locked out to prevent unauthorized operation of the gates.

- There is no preventative maintenance program for the gates and hoisting equipment. Since 2009, there has been no maintenance performed on the equipment. A maintenance program should be developed.

- The sensor on the south gate actuator indicating overheating is faulty and should be corrected.

- The bottom seal on the north gate is damaged in the centre, resulting in leakage under the gate when fully closed, and should be replaced.

- The electrical cabinet grounding cable is disconnected from the grounding rod, and bond connection to fence is not sufficient to provide adequate grounding. The grounding connection should be reinstated.

- According to the operations personnel, ice forms over the entire face of the gate skin plates during the winter. Operations staff noted there is no specific guidance for the water level that should be maintained prior to freezing in the winter; however, the level is monitored via the level sensor and kept low (approximately <2 m). Ice sheets collect behind the gate during the winter and build-up is exacerbated during freeze-thaw cycles. The ice heaves up the wing walls of the structure. The ice thickness reaches approximately 40 cm; this measurement was noted during ice fracture; however, specific ice thickness measurements are not currently collected. It was discussed that during the winter of 2020/21, ice thickness measurements should be collected by the City to improve the understanding of the ice loading on the gates.

- In January 2021, the ice thickness was measured by the City staff by drilling holes into the ice within the reservoir. The maximum thickness measured was approximately 560 mm. City staff noted that winter 2020-2021 has been unseasonably warm and measured ice thickness may not be representative of a normal scenario. The ice sheet within 20 m upstream of the dam has collapsed a few times this year, where normally that would not happen until spring.

4.2.5 Outlet Channel

The shorelines slopes of the outlet channel are generally in good condition, with no major indications of instability and only minor erosion observed. The channel is armoured with gabions immediately downstream of the spillway chute, and well vegetated with a mixture of trees, native grasses, bushes, and shrubs beyond the gabions.

Maintenance and monitoring issues noted during the inspection of the outlet channel shorelines are summarized below:

- The riprap (and gabions) downstream of the spillway should be designed to prevent eddies forming adjacent to the guide walls and prevent erosion issues. This would be part of an overall dam upgrade, although some mitigation could be achieved using larger riprap.

- There is a sizeable amount of displaced riprap just beyond the bottom of the stilling basin. It is unclear where this riprap came from, as the gabions all appear to be in place and intact. It is suspected that the channel riprap may have been eroded from the channel bottom adjacent to the stilling basin, which will be verified during the inspection of the de-watered spillway in 2021.

4.3 Staff Interview and Questionnaire

Prior to the dam safety inspection, SNC-Lavalin prepared a list of questions on dam safety management and other technical aspects of the dam and spillway and submitted it to the City. The intent of the questionnaire was to gather relevant information to prepare for the site inspection and to engage City dam safety staff in the process. City staff added their responses for each of the 68 questions which were received and reviewed by SNC-Lavalin after the site inspection. The SNC-Lavalin DSR Team interviewed City staff during the site inspection to collect additional information, where necessary. The completed questionnaire with answers is provided in Appendix II.

The questionnaire was broken down into topical sections with questions for each section, as follows:

- Dam Safety Management – 13 questions;
- Operations, Maintenance, and Surveillance – 12 questions;
- Emergency Preparedness – 4 questions;
- Geotechnical – 10 questions;
- Hydrotechnical – 15 questions; and
- Mechanical & Electrical – 14 questions.

4.4 Survey

As a part of the site inspection, SNC-Lavalin retained GeoVerra Inc. (GeoVerra) to complete a one-day profile survey of the dam and spillway on October 15, 2020.

City staff provided access to the dam and spillway to the survey team as required. The profile survey was conducted using a Real Time Kinematic Global Positioning System (RTK-GPS) with vertical accuracy of ±0.050 m and horizontal accuracy of ±0.020 m. Key components of the survey and the dam topography are shown on the appended Drawing 3 and selected cross-sections of the dam are shown on the appended Drawing 4.

5 Hydrology Update and Hydrodynamic Modelling

5.1 Flood Hydrology Update

The main objective of the hydrological update is to review and update the design flow by incorporating data available since the last (2013) DSR report. Details of the review and update are presented in Appendix III.

5.1.1 Data Review and Analysis

The Bear River is a tributary to the Wapiti River which drains into the Smoky River and ultimately to the Peace River. The 1,566 km^2 watershed area upstream of the Bear River Reservoir includes the Bear Lake with a surface area of 33 km^2 which plays a significant role in the attenuation of the peak flows to the reservoir.

Key Water Survey Canada (WSC) stations used in the assessment of the peak flows are:

- WSC 07GE003: a long-term (1969 to 2018) hydrometric station on the Grande Prairie Creek and watershed area of 140 km^2.
- WSC 07GE005: a discontinued hydrometric station on the Bear River with only four years of data (1983 to 1986) and watershed area of 1,510 km^2.
- WSC 07GE004: a long-term (1967 to 2009) water level gauging station on the Bear Lake and watershed area of 1,190 km^2.

Recorded fluctuations of the Bear Lake water level over the record period of 1960 to 2009 ranged from El. 662.80 to 665.80 m with the highest elevation recorded in 1974. An assessment of the rating curve of the reservoir was carried out based on the water level record at WSC 07GE004 and the discharge records at WSC 07GE005 and WSC 07GE003 for the four years of concurrent records for the period between 1983 and 1986. The reconstituted rating curve, which assumes conservatively that the discharge is free of backwater, indicated that the maximum discharge water level from the lake was of around 19 m^3/s.

For the update of the various return period flows to the reservoir, the Grande Prairie Creek data (WSC 07GE003) was analyzed. Flood frequency analysis on the historical time series of daily annual maximum flow data was performed and Lognormal III distribution was the best fit for the station. The peak discharge was scaled for the entire watershed downstream of Bear Lake to the Bear River Reservoir (140 km^2 at WSC 07GE003 and 422 km^2 in total) using a regional equation. The regional exponent coefficient of the equation was determined based on the recorded peak discharges at WSC 07GE005 and 07GE003 for the period 1983-1986. A coefficient of 0.6 was found to produce the best transposition of peak discharges between watersheds.

The various return period flows of the Grande Prairie Creek are upscaled to the watershed downstream of the gauging station. From the above review, the following assumptions were made to estimate total inflows to the reservoir and the resulting estimated maximum daily flow is provided in **Table 5.1**:

- Bear Lake outflow at the confluence with Grande Prairie Creek for return periods up to 1,000-year is assumed as 20 m^3/s based on the available Bear Lake water level data and comparison of Bear River and Grande Prairie Creek recorded hydrographs.

- Previous studies noted that part of the Grande Prairie Creek flow at the confluence with the Bear River flow is reversed to the Bear Lake. For this study, the flow reversal to the Bear Lake for flood events up to the 1,000-year flow is estimated to be 10%.

Table 5.1 Estimated Bear River Reservoir Maximum Daily Inflows

Return Period (years)	Daily Peak Flows (m^3/s)
2	33
5	46
10	56
100	100
500	141
1,000	162

5.1.2 PMF Review

The 2014 DSR Probable Maximum Flood (PMF) estimate for the Bear River Reservoir is 750 m^3/s. The estimate was done using the Creager Diagram in Alberta Transportation Guidelines on Extreme Flood Analysis (AT 2004). The current study reviewed the PMF using the same widely used flood envelope diagram of Creager for the peak discharge against drainage area. The PMF was estimated for the total watershed area 1,566 m^3/s using C value of 20. Assuming 50% attenuation of the PMF within the Bear Lake, the estimated PMF for the project is 783 m^3/s.

The 2014 DSR estimated the 24-hour point Probable Maximum Precipitation (PMP) for the Bear River using Hopkinson (1999) and Taylor and Hogg (2006) with a point PMP of 466 and 460 mm. The area adjusted 24-hour PMP for the project was estimated as 210 mm. For the current study, review of these PMP values was conducted using a statistical method approach proposed by Hershfield as stated in the Alberta Transportation manual. The method is based on the sample mean and sample standard deviation of the annual maximum precipitation sample and a multiplication factor applied to the standard deviation to obtain the probable maximum precipitation. The 24-hour point PMP estimated using this approach is 445 mm. Considering the uncertainties involved around estimation of PMP and PMF and the minor difference between the current review and the previous study, the 2014 DSR value for the PMF, 750 m^3/s, is applied for the current study.

5.1.3 Flood Hydrographs

The daily observed flows of the Bear River gauged data at Grande Prairie (1983 to 1986) were reviewed to develop the inflow hydrographs. Based on this review, the unit hydrograph developed in the 2014 DSR is found to be representative of the observed hydrographs. The unit hydrograph was used to scale up the various flood events for the current study. **Figure 5.1** presents the updated flood hydrograph into the Bear River Reservoir.

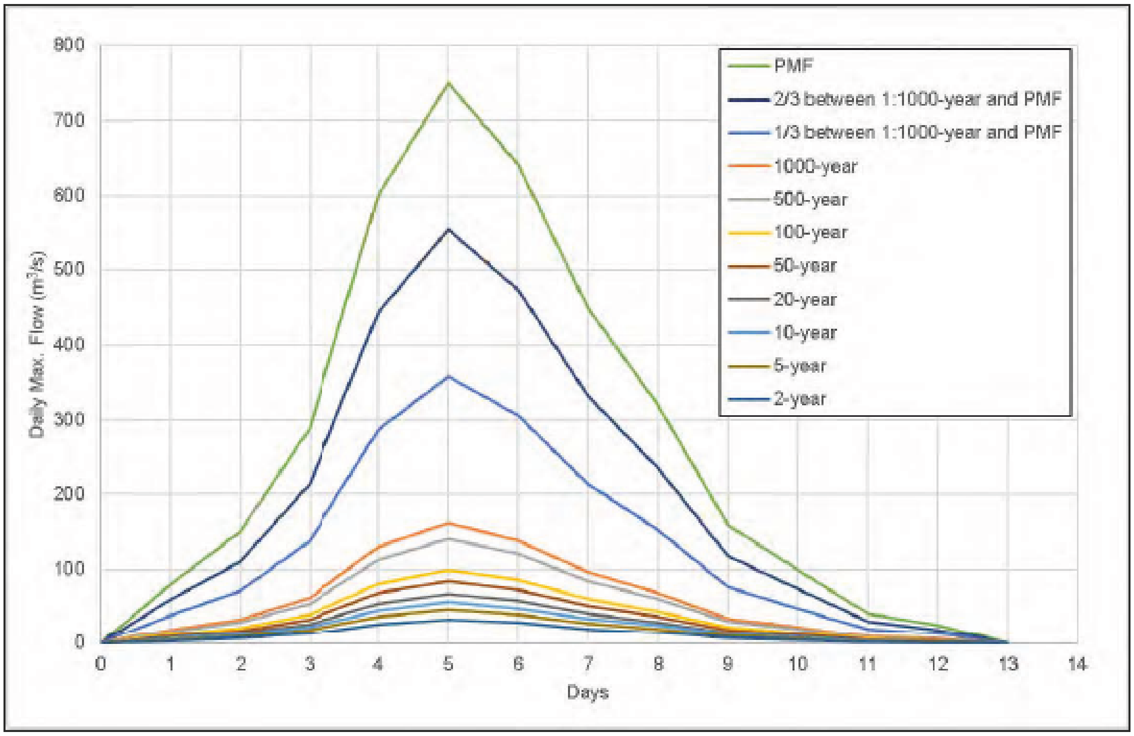


Figure 5.1 Flood Hydrographs into Bear River Reservoir

5.2 Hydrodynamic Model Setup and Calibration

The hydrodynamic modelling for the Bear River is set up using the Hydrologic Engineering Center River Analysis System (HEC-RAS) version 5.0.7 one dimensional (1D) unsteady state flow model. Northwest Hydraulics (NHC) developed a 1D steady state HEC-RAS model, for the City of Grande Prairie Flood Risk Mapping. NHC surveyed 47 channel cross-sections and extended the channel cross-section using DEM-derived contours and provided data on six river crossings (four bridges, one rail bridge, and one sewer crossing). The NHC model was developed in two sections, upstream of the reservoir and downstream of the dam. The model was reported to be calibrated using various parameters, mainly Manning's roughness coefficient "n" and an approximate estimate of the 1990 flood flow and high watermark recorded for the period.

SNC-Lavalin extracted the NHC calibrated model cross-sections, roughness coefficients, contraction and expansion values, and the data for the river crossings. For the current study, the two upstream and downstream river stretches were merged with the middle reservoir stretch cross-sections provided by the City as a bathymetry data. The combined river stretch of the Bear River has an approximate length of 20.2 km. The cross-section data was georeferenced and checked for its quality. The Bear River control structure information obtained from the design drawings of the structure is included in the merged river network. The medium range Manning's "n" from NHC model was adopted with the channel values ranging from 0.035 to 0.05 and the bank value ranging from 0.05 to 0.18.

Reservoir routing can be conducted using level pool routing or full dynamic wave routing. The most accurate modelling technique for long narrow reservoir is full dynamic wave unsteady flow routing (which uses full Saint Venant equation) for dam break analysis. Considering the reservoir depth, length, and availability of data, a full dynamic wave routing approach is found to be best suited and is used for the Bear River Reservoir.

Stability of the model is an issue in unsteady state flow 1D HEC-RAS model. To overcome the stability issues encountered in the Bear River model, the following measures were taken:

- Minor adjustments of roughness coefficient (Manning's "n").
- Interpolation of more cross-sections between the original sections.
- Removal of the downstream bridge at 99 Avenue. The existence of two bridges so close to each other created some interference between the two computed rating curves, leading to non-physical phenomenon. Only the bridge with the smaller opening, creating the most sever obstruction, was kept in the model. This is expected to have very little impact on the modeling results.

For the upstream boundary condition, unsteady state flow hydrographs of 2, 5, 10, 100, 1,000-year 24-hour flood events and $^1/_3$ between 1,000-year and PMF, $^2/_3$ between 1,000-year and PMF, and PMF were applied. For the downstream boundary condition, the channel slope, measured from the downstream channel invert, was applied.

5.2.1 Dam Breach Modelling

A dam break model was established to update or confirm the current consequences of the Bear River Dam. A 1D unsteady state HEC-RAS model was used to simulate the dam breach process and determine breach outflow and water-surface profiles in downstream reach of the river. Dam breach hydrographs from dam failure are routed downstream of the dam to determine the flood arrival time, peak flow, and the depth of flow at downstream locations. Mapping of the inundation areas is used to confirm or update the consequence classification of the Bear River Dam.

The CDA DSG (2007, revised 2013) identify two initial hydrologic conditions for the worst-case dam breach scenario:

- Fair weather or sunny day failure scenario: failure occurs during normal operation and no associated hydrologic events; the main failure mode for this type of failure is piping of the dam; and
- Flood induced or rainy-day failure scenario: failure occurs during a flood event; the main failure mode for this type of failure scenario is overtopping of the dam.

For the Bear River, the fair-weather scenario is not considered, as the reservoir is almost empty most of the year except when there is rainfall in the watershed. The dam breach modelling was conducted for both piping and overtopping scenarios under flood induced scenario.

Estimation of dam breach location, dimensions, and development time are critical in the assessment of a dam's potential risk (USACE 2014). For the Bear River dam breach parameters, various earth fill dam suggested case study parameters have been reviewed. The parameters for this project were established based on the 1995 Froehlich regression equation provided below.

$$B_{ave} = 0.1803\ K_o\ V_w^{0.32}\ h_b^{0.19}$$

$$t_f = 0.00254 V_w^{0.53}\ h_b^{-0.9}$$

Where:

B_{ave} = average breach width (metres)

K_o = constant (1.4 for overtopping failures, 1.0 for piping)

V_w = reservoir volume at the time of failure

h_b = height of the final breach (metres)

t_f = breach formation time (hours)

With breach side slope of 0.1H:1V and final breach height of 4.75 m, the computed bottom breach width and failure time are considered for the Bear River Dam area 23.8 m and 0.74 hours, respectively. The dam breach parameters used in the modelling are provided in **Table 5.2**.

Table 5.2 Dam Breach Parameters Used

Parameter	Sunny Day	Flood Induced
Dam Crest Elevation (m)	655	655
Reservoir Level at time of breach (m)	654	655.2
Effective Height (m)	4.75	4.75
Breach top width (m)	25	25
Breach width at bottom (m)	24	24
Time to failure (h)	0.74	0.74
Breach side slope (Z)	0.1	0.1

With both gates fully open, when the 100-year and 1,000-year flood events are simulated, the reservoir does not overtop the dam; hence, it is assumed the dam will fail through piping at the peak flood event. For the remaining larger flood events, the dam was simulated to fail when the reservoir levels overtop the dam and breach is happening at the peak of the flood event. The 2018 bathymetry data of the reservoir shows that the reservoir completely lost its dead storage due to sediment deposition and almost acts as a river. Since the reservoir lost dead storage capacity, no or minor attenuation of the flood is expected in the reservoir.

5.2.2 Sensitivity Analysis of Breach Parameters

Assigning appropriate breach parameters is important since the parameters will affect the breach outflow hydrograph and consequences of dam failure. Hence, sensitivity of the breach parameters is conducted within the HEC-RAS model to quantify the magnitude of the effects on breach outflow and downstream water surface. The sensitivity was conducted by increasing/decreasing the breach time and breach width on the 100-year flood event. This analysis helped to better understand the impact of the assumed parameters on the inundated areas. **Figure 5.2** provide the effects of changing the breach time from 0.5 to 0.74 and to one hour and changing the breach bottom width from 12 m to 18 m and to 24 m. As shown in the figure, both parameters are sensitive to breach development. For this study, a breach time of 0.74 hours and a breach width of 24 m is found to be appropriate.

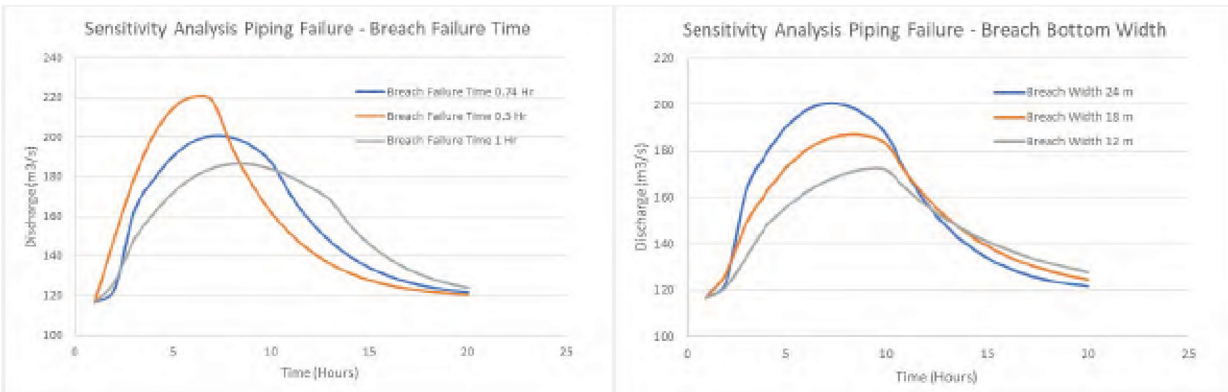


Figure 5.2 Sensitivity Analysis Piping Failure – Breach Failure Time and Breach Bottom Width

5.2.3 Flood Routing

The HEC-RAS unsteady state flow model was run for both with and without dam breach for the following flood events:

- 100-year;
- 1,000-year;
- 1/3 between 1,000-year and PMF;
- 2/3 between 1,000-year and PMF; and
- PMF.

The surface water profiles from modelling scenarios with and without dam breach are presented in **Figure** 5.3. The modelling started with the 100-year flood event and review of the inundated surface area, incremental depth, and velocity. The model run and analysis of incremental inundation area, depth, and velocity continued up to PMF. The maximum incremental depth for the failure under a flood 2/3 between 1,000-year flood and PMF and under the PMF was minimal (between 0.30 m and 0.60 m); hence, no further investigation on these larger events was necessary. Flood routing results at the BRCS for the 100-year flood, 1,000-year flood, 1/3 between 1,000-year flood and PMF, 2/3 between 1,000-year flood and PMF, and PMF are presented in **Figure 5.4**, **Figure 5.5**, **Figure 5.6**, **Figure 5.7**, and **Figure 5.8**, respectively. All the modelled flood events for both the breached and no-breach scenarios are confined within the Bear River valley corridor.

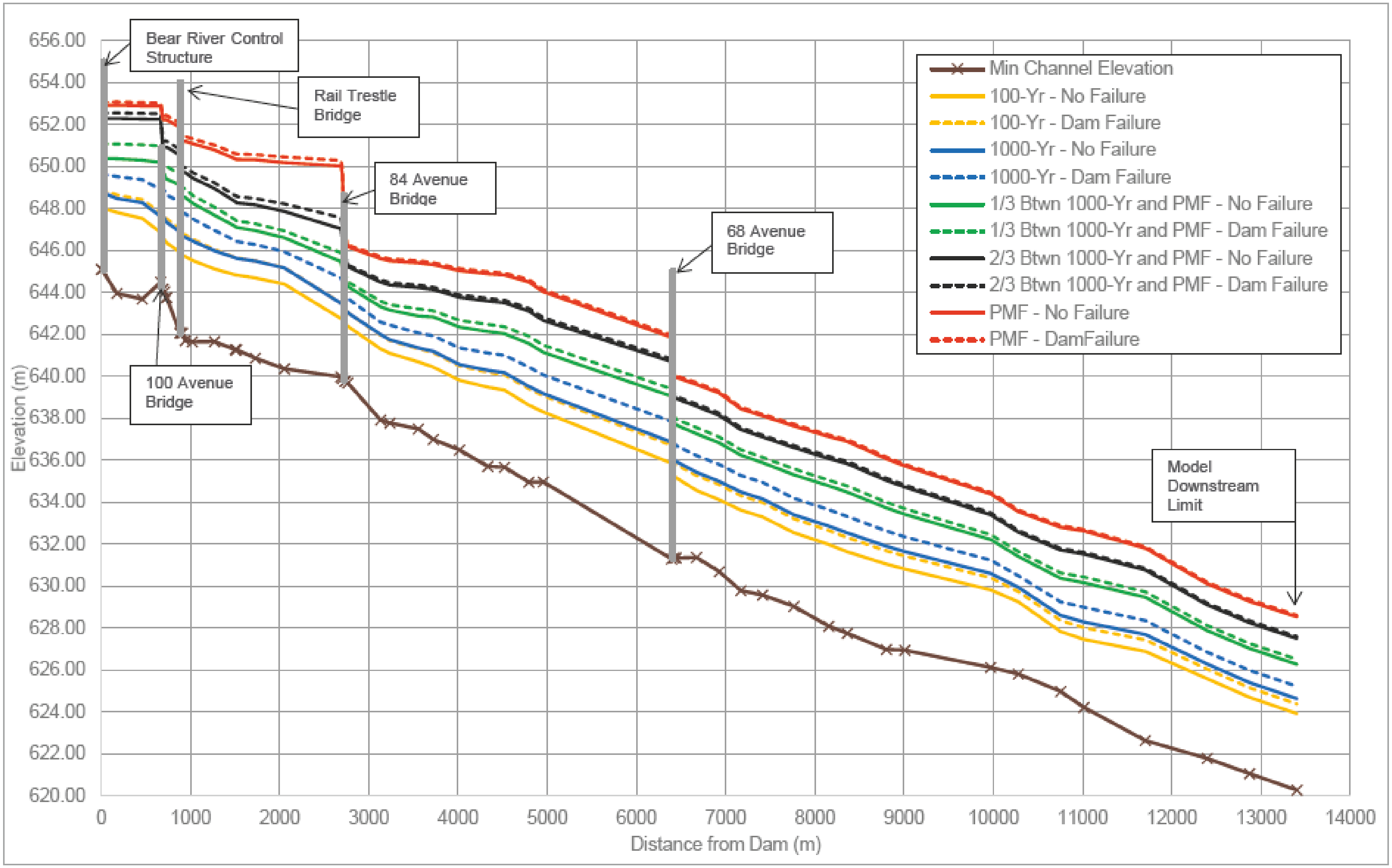


Figure 5.3 Downstream Surface Water Profiles – With and Without Dam Failure

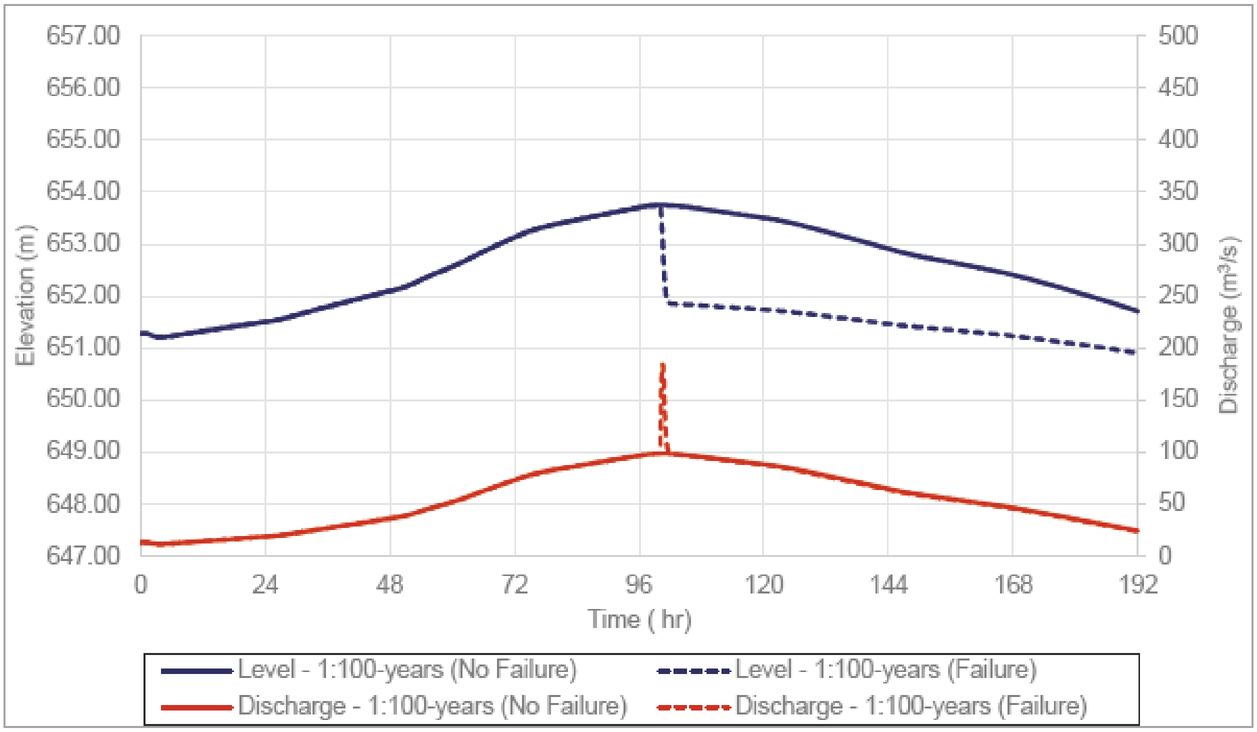


Figure 5.4 Flood Routing Results at Bear River Control Structure – 1:100-year Flood

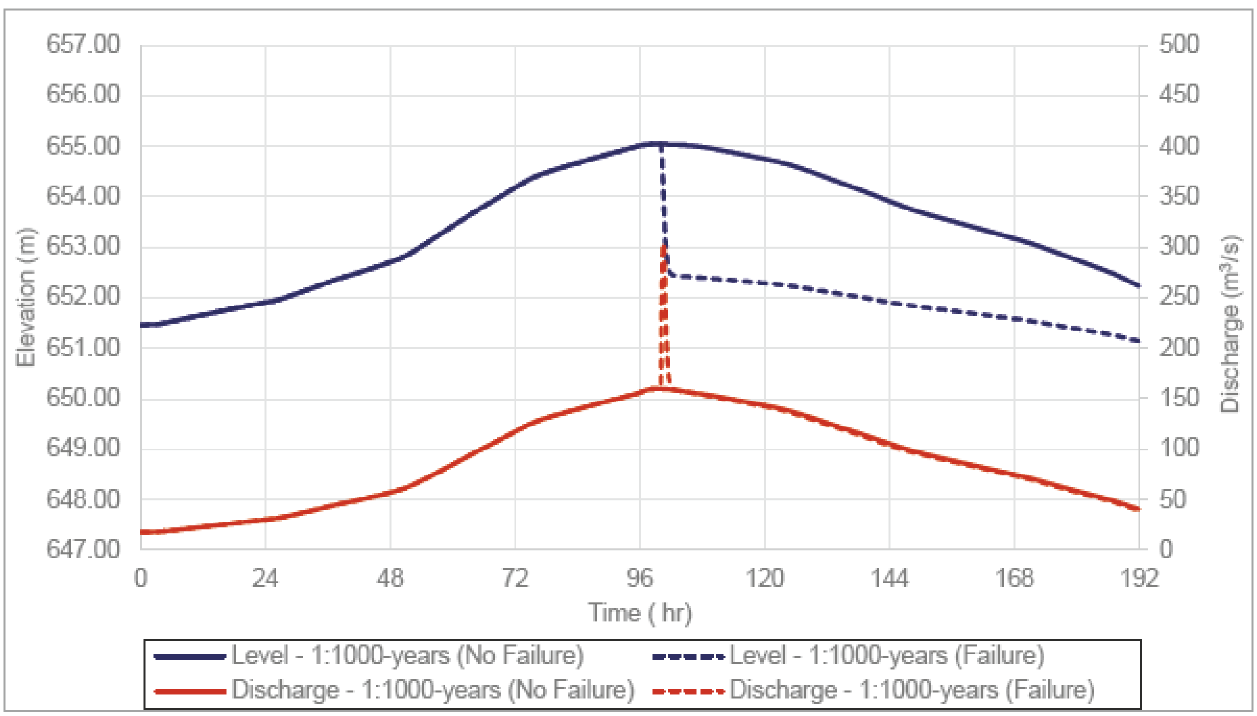


Figure 5.5 Flood Routing Results at Bear River Control Structure – 1:1000-year Flood

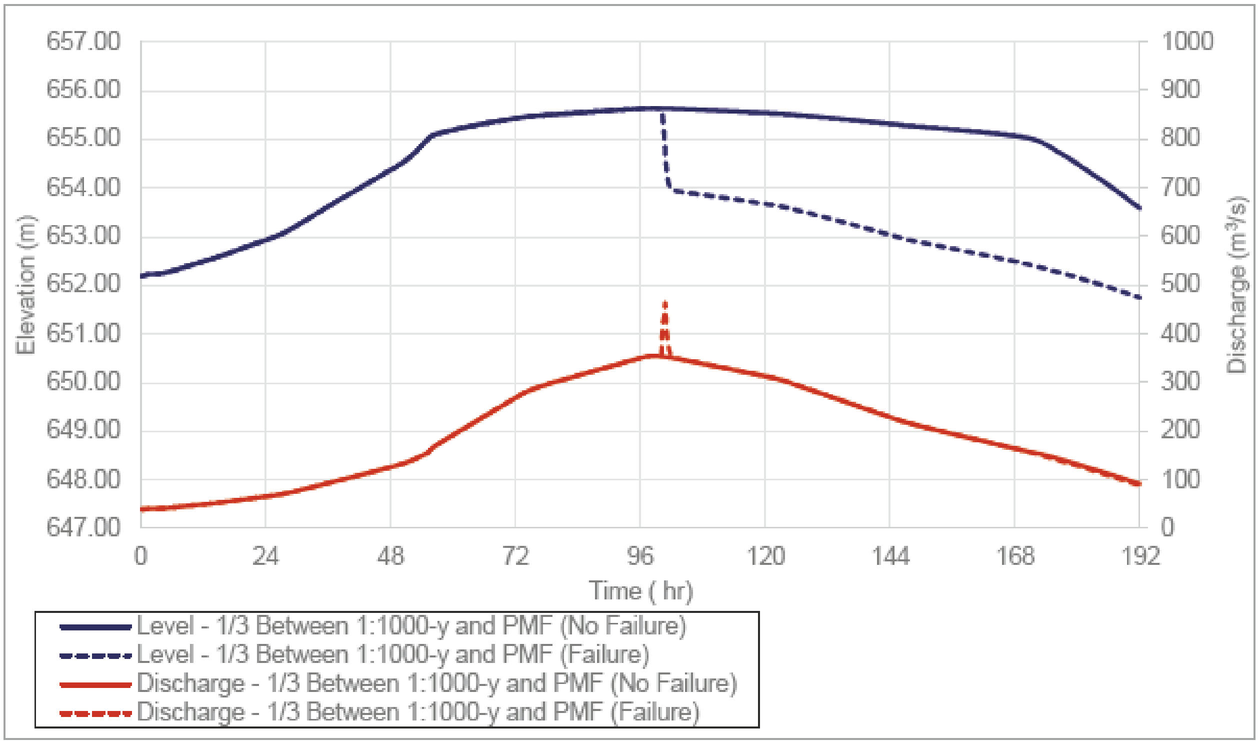


Figure 5.6 Flood Routing Results at Bear River Control Structure – 1/3 between the 1:1000-year Flood and the PMF

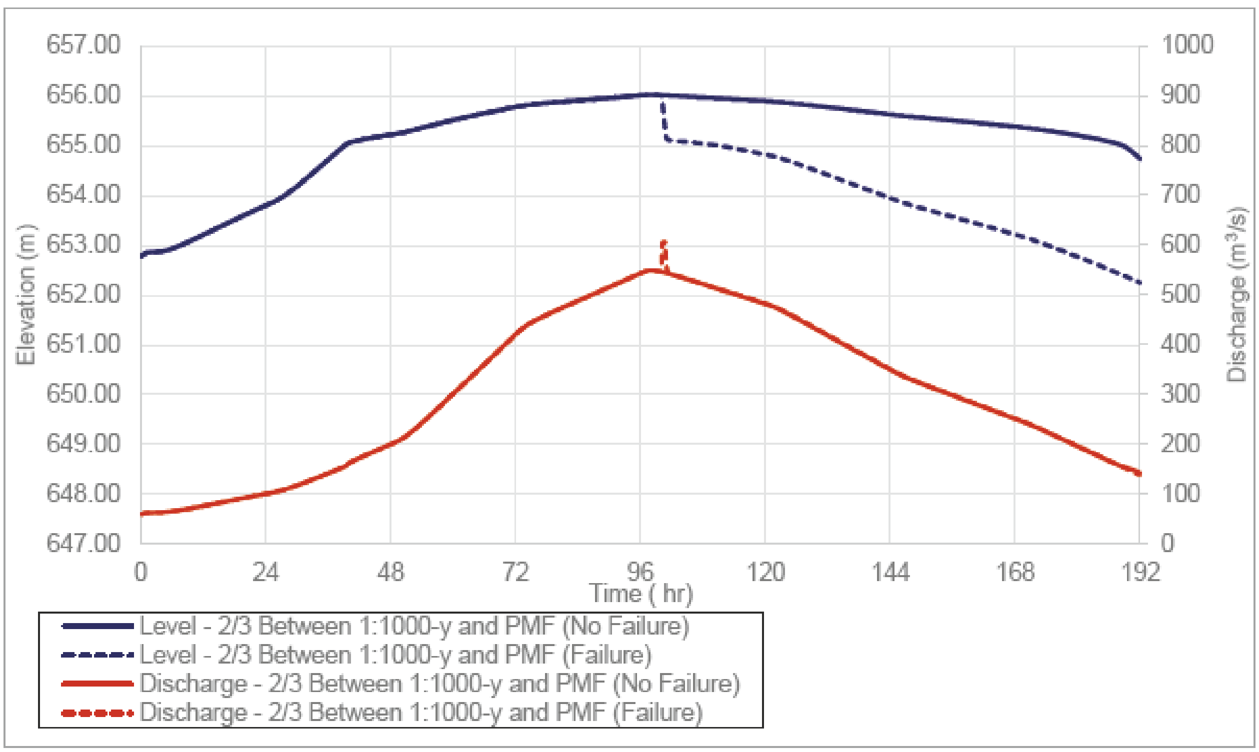


Figure 5.7 Flood Routing Results at Bear River Control Structure – 2/3 between the 1:1000-year Flood and the PMF

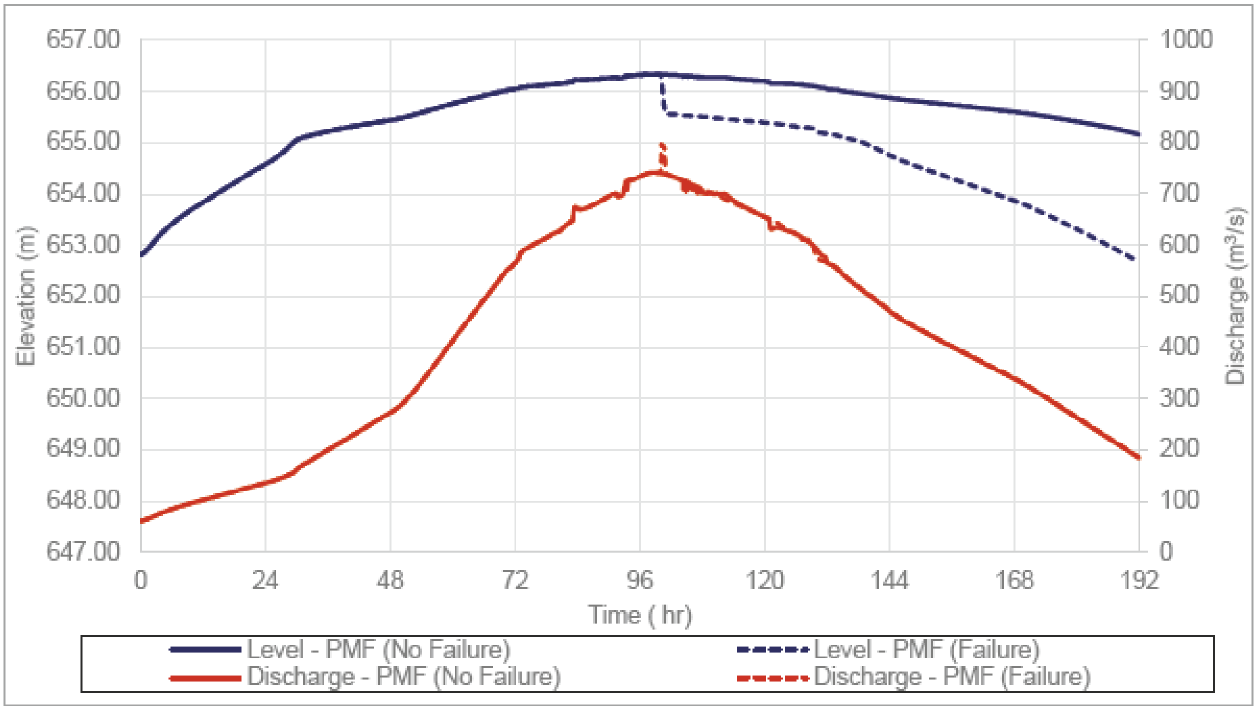


Figure 5.8 Flood Routing Results at Bear River Control Structure – PMF

6 Reassessment of Consequence Classification

6.1 Introduction

According to the CDA 2007 DSG and the 2013 Revision (CDA 2013), the Consequence classification of a dam is used primarily to identify:

› an appropriate Inflow Design Flood (IDF) and Earthquake Design Ground Motion (EDGM);

› the frequency of future DSRs;

› the level of detail required in the EPP, ERP, and OMS for the dam; and

› the level of effort required for overall dam safety management oversight.

The CDA (2013) DSG provides a classification system that can be used to guide the standard of care expected from dam owners and designers for safe operation of dams. The system is based on the potential incremental consequences of a dam failure.

In 2018, the Government of Alberta published the Alberta Dam and Canal Safety Directive (ADCSD; GoA 2018) that provides the criteria to determine the incremental consequences of a dam failure. The criteria, along with IDF specifications from CDA (2013) Dam Safety Guidelines (following the traditional standards-based approach), are reproduced in **Table 6.1**. The criteria in the ADCSD (GoA 2018) are very similar to those in the CDA (2013) DSG. Key additions, changes, or differences in the 2018 ADCSD criteria compared to the CDA (2013) guidelines criteria are shown as *italics* in **Table 6.1**.

Currently, the City operates and maintains the Bear River facility as a Significant Consequence structure following the most recent DSR carried out by Golder (Golder 2014). An inundation study and update to the consequence classification of the Bear River facility was carried out as part of the 2020 DSR. The classification was reviewed taking both the CDA (2013) guidelines and the 2018 ADCSD into consideration.

Table 6.1 Classification of Dams According to the 2018 Alberta Dam and Canal Safety Directive, and IDF Selection According to the CDA 2007 Dam Safety Guidelines

Consequence Classification	Population at Risk (PAR)	Incremental Consequences of Failure			Annual Exceedance Probability Traditional Standards-Based Criteria	
		Loss of Life (LOL)	Infrastructure and Economic, and other property Losses	Environmental and Cultural Losses	IDF	EDGM
Low	None identifiable	*No possibility of loss of life other than through unforeseeable circumstances*	Minimal economic losses *mostly limited to the dam owner's property, and no potential for development within the dam inundation zone.*	Minimal short-term loss or damage and no long-term loss or damage to: *Fisheries* *Wildlife habitats* *Rare or endangered species* *Unique landscapes, or* *Sites of cultural significance*	1:100	1:100
Significant	Temporary only	*Low potential for loss of life*	Low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction or damages to locations used occasionally and irregularly for temporary purposes.	No significant loss or damage to Important fisheries Important wildlife habitat *Rare or endangered species* *Unique landscapes, or* *Sites of cultural significance* Restoration or compensation in kind highly possible.	Between 1:100 and 1:1,000	Between 1:100 and 1:1,000
High	Permanent	10 or fewer	High economic losses affecting infrastructure, public, transportation *or services or* commercial facilities, *or some destruction or severe damage to scattered residential buildings.*	Significant loss or damage to Important fisheries Important wildlife habitat *Rare or endangered species* *Unique landscapes, or* *Sites of cultural significance* Restoration or compensation in kind for losses and damages highly possible.	1/3 between 1:1,000 and PMF	1:2,475
Very High	Permanent	100 or fewer	Very high economic losses affecting important infrastructure, public, transportation or services *or* commercial facilities, *or some destruction or severe damage to residential areas.*	Significant loss or damage to critical fisheries critical wildlife habitat *rare or endangered species* *Unique landscapes, or* *Sites of cultural significance* Restoration or compensation in kind for losses and damages possible but impractical.	2/3 between 1:1,000 and PMF	1/2 between 1:2,475 and 1/10,000 or MCE
Extreme	Permanent	More than 100	Extremely high economic losses affecting critical infrastructure, public, transportation or services *or* commercial facilities, *or some destruction or severe damage to residential areas.*	Major loss or damage to critical fisheries critical wildlife habitat *rare or endangered species* *Unique landscapes, or* *Sites of cultural significance* Restoration or compensation in kind for losses and damages is impossible.	PMF	1/10,000 or MCE

Note (1) Definitions for population at risk:

None: there is no identifiable population at risk, so there is no possibility of LOL other than through unforeseeable misadventure.

Temporary: people are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent: the population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential LOL (to assist in decision-making if the appropriate analysis is carried out).

Note (2) Implications for LOL:

Unspecified: The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

6.2 Evaluation of Incremental Loss

According to the CDA (2013) guidelines, the standard of care and due diligence expected of a dam owner relates to the incremental losses due to a dam failure; that is, losses above and beyond those that would have occurred due to a natural event if the dam had not failed. The incremental consequences of failure are defined as the total consequences from an event with dam failure minus the consequences that would have resulted from the same event had the dam not failed. The incremental consequence classification of a dam takes into consideration consequences that fall into three broad categories: (1) potential loss of life, (2) infrastructure and economic losses, and (3) losses of environmental and cultural values. The incremental losses were evaluated for 100-year, 1,000-year and $^1/_3$ between 1,000-year and PMF events.

The Bear River flow downstream of the dam is confined within the Bear River valley. Within the valley, there are several river crossings, major highway bridges, pedestrian bridges, and pipeline crossings. Immediately downstream of the dam, there is the Muskoseepi Park where the Grande Prairie Museum and the Heritage Village are located. No residential properties are located within the flood path and within the Bear River valley. In this section, the incremental losses have been evaluated for loss of life, environmental and cultural loss, and structural loss.

6.2.1 Loss of Life

The CDA guideline states that the Permanent Population at Risk (PAR) in an inundated area provides an indication of the number of people exposed to the hazard. The Alberta Dam and Canal Safety Directive, 2018 defines the PAR is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents) while for the temporary population at risk are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

For the Bear River, there are no residences along the dam breach flood path; therefore, no permanent population at risk. The temporary population at risk includes recreational users of City of Grande Prairie Museum, traffic on roads or bridges crossing the river, and people using the pedestrian path. For the temporary population at risk, the consequence classification assigned by the directive is “Significant”.

6.2.2 Environmental Loss

The Bear River is a fish-bearing tributary to the Wapiti River and is part of the Smoky/Wapiti sub-basin of the Peace River Watershed. The River is a Class C Waterbody with a Restricted Activity Period (RAP) between April 16 and July 15 (GOA 2006). Fish species located within the study area, as per FWMIS, are listed in Appendix IV. None of the native or stocked fish species encountered within the study area are protected under Species at Risk Act (SARA). However, all native and stocked species present are protected under the Fisheries Act and all are considered secure at a provincial level.

Short-eared owls (Asio flammeus) were identified in the study area and are considered Special Concern under SARA. Short-eared owls nest in grassland habitats where small mammal prey is abundant (Clayton 2000). This type of habitat may be present in the upland areas adjacent to the Bear River. None of the other wildlife species identified are protected under SARA, although remain protected under the Migratory Birds Convention Act, 1994. Additional rare species identified (Appendix IV) have Sensitive to May be at Risk statuses under the Alberta Wildlife Act. Trumpeter swans (Cyngus buccinator) are of significant consideration as they make abundant use of the Grande Prairie area during migration and breeding.

Areas of cultural significance and heritage resources are located directly downstream of the Bear River Control Structure (BRCS) and within Muskoseepi Park along Bear River. Based on a review of the Alberta Listing of Historical Resources, the study area has a historical resource value (HRV) of five, which designates a high potential to contain historic resources. In these areas, the primary historic resource categories are archaeological and palaeontological (GOA 2020). The Grande Prairie Museum and the Heritage Village is also located within the park.

The anticipated consequence classification rating for each environmental category (AEP 2019) and each flood event considered for the study are presented in **Table 6.2**. The overall environmental loss classification is for this project is considered to be "significant".

Table 6.2 Environmental Loss Consequence Classification

Impact Category	100-year Incremental Consequence	1,000-year Incremental Consequence	$^{1}/_{3}$ Between 1,000 and PMF Incremental Consequence
Fish and Fish Habitat	Significant	Significant	Low
Wildlife	Low	Low	Low
Species at Risk	Low	Low	Low
Unique Landscapes	Low	Low	Low
Sites of Cultural Significance	Low	Low	Low
Overall	**Significant**	**Significant**	**Low**

6.2.3 Infrastructure and Economics

An assessment of infrastructure loss downstream of the Bear River dam during dam breach includes the Muskoseepi Park which houses the Grande Prairie Museum and the Heritage Village, river crossings such as highway bridges, pedestrian bridges, rail crossings, and pipeline crossings. For the assessment of loss, the following are assumed:

› For the river crossings (road bridges, railway bridges, and sewer crossings), freeboard less than 0.5 m is expected to cause some damage while a peak flow reaching the deck is assumed to cause total failure.

› Pedestrian bridges are designed to be low head river crossings and total failure occurs when the peak flow tops the deck.

› Damages to the Grande Prairie Museum and the Heritage Village could range from cleaning to complete wipe out. Flow depth greater than 2 m is assumed to cause total damage.

Downstream of the dam, there are 12 pedestrian bridges and two pipeline crossings with no data. The incremental assessment was conducted based on the pedestrian bridges deck and pipeline elevation obtained from the LiDAR data.

For infrastructure and economic, the incremental loss due to inundation of areas, flood depth, and velocity for the 100-year, 1,000-year and $^{1}/_{3}$ between 1,000-year and PMF events and for both breached and no-breach scenarios are assessed below.

100-year Flood Event

For the failure during the 100-year flood event, the incremental depth in the modeled area ranges from 0.46 m to 1.21 m. During this flood event, all the major highway crossings can safely pass the peak flow with more than 0.5 m freeboard and no damage is expected to the major crossings for both failure and non-failure scenarios. No pedestrian bridge is overtopped during the no-failure scenario while only one pedestrian bridge is overtopped under breach flood wave. Part of the Heritage Village is inundated due to dam breach. Most of the stormwater outlets are flooded during the 100-year event without dam failure. Overall, the incremental damage for the 100-year flood event is considered to be "Low" consequence.

1000-year Flood Event

For the failure during the 1000-year flood event, the incremental depth in the modeled area ranges from 0.56 m to 1.44 m. All the major highway crossings can safely pass the peak flow with more than 0.5 m freeboard and no damage is expected to the major crossings. One of the pedestrian bridges is overtopped during the non-failure scenario and seven more pedestrian bridges are overtopped under the breach scenario. The Heritage Village is inundated during the 1,000-year without a dam failure. The dam breached scenario inundates the Museum building, with water depth limited to a maximum of 1.0 m. Overall, the incremental damage for the 1,000-year flood event impacts six pedestrian bridges and the flooding of the Museum building area. Considering the number of pedestrian bridges being wiped out, the 1,000-year event is considered to have a "Significant" consequence.

One Third Between 1,000-year and PMF

For this event, the average modeled incremental depth ranges from 0.23 m to 0.79 m. The incremental inundation area is very limited. No major highway crossing is overtopped for both non-failure and failure scenarios. Eleven of the pedestrian bridges are overtopped during the flood routing, without a dam breach. The Museum and the Heritage Village are fully inundated under both failure and non-failure scenarios. Overall, the incremental loss for this flood event is minimal; therefore, assigned with "Low" consequence classification.

6.2.4 Summary of Consequence Classification

Assessment of the potential incremental loss of life, environment, and cultural loss as well as infrastructure and economic loss is presented in **Table 6.3**. Based on the above assessment, it is recommended to retain the consequence classification "Significant" for the Bear River control structure.

Table 6.3 Summary of Failure Consequence Classification

Category	100-year Incremental Consequence	1,000-year Incremental Consequence	1/3 Between 1,000 and PMF Incremental Consequence
Loss of Life	Significant	Significant	Low
Environmental and Cultural	Significant	Significant	Low
Infrastructure and Economics	Low	Significant	Low
Overall	**Significant**	**Significant**	**Low**

7 Hydrotechnical Analysis

7.1 Inflow Design Flood

The CDA (2013) DSG suggests the use of the Traditional Standards Based Approach and/or the Risk-Informed Approach to determine the Annual Exceedance Probability for flood. **Table 7.1** provides the proposed IDF for dams based on their incremental consequence category for the Traditional Standards Based Approach.

The Bear River dam classification assessment confirms the dam classification as "Significant". For this consequence classification, the IDF as per the CDA 2013 is between the 100-year and 1,000-year flood event. Considering that the incremental damage is limited, the 1:500-year flood event is considered the recommended IDF for the Bear River Control Structure.

Table 7.1 Flood and Earthquake, Standards-Based Approach (CDA, 2013)

Dam Class	Annual Exceedance Probability	
	Inflow Design Flood (IDF)	Earthquake Design Ground Motion (EDGM)
Low	1/100-year	1/500-year
Significant	Between 1/100 and 1/1,000-year	1/1,000-year
High	$^{1}/_{3}$ between 1/1,000-year and PMF	1/2,500-year
Very High	$^{2}/_{3}$ between 1/1,000-year and PMF	1/5,000-year
Extreme	Probable Maximum Flood (PMF)	1/10,000-year

7.2 Earthquake Design Ground Motion

The EDGM is determined based on the incremental consequence of a sunny-day dam breach assessment. Since the Bear River reservoir is most of the time with little or no stored volume of water, and since the hydraulic analyses of dam breach during flood indicated that the flow is generally contained in the river bed, the sunny-day breach analysis was omitted and instead the consequence classification "Significant", equivalent to the rainy-day classification result, was estimated for the Bear River Control Structure. The recommended EDMG for the structure is 1,000-year annual exceedance probability earthquake (**Table 7.1**).

7.3 Inundation Mapping

The development of flood inundation mapping for the Bear River floodplain used data sources that cover all relevant aspects of the modelling and damage assessments. Accordingly, the City of Grande Prairie provided the following data in support of this project:

› River cross-section from previous study;

› LiDAR Data;

› Major bridges information obtained from previous HEC-RAS model;

- Storm outfall locations; and

- Pedestrian bridge crossings obtained from LiDAR data.

For the mapping, HEC-GeoRAS module and ArcGIS tool are used to create a HEC-RAS import file from the geospatial data. Water surface profiles are exported from HEC-RAS and are processed in HEC-GeoRAS to visualize the flood inundation extent.

As per the consequence classification of "Significant", the IDF for the Bear River Dam is the 500-year flood event. Inundation maps were prepared and are attached under Inundation Mapping. At each major crossing along the river, the maps present maximum depths, peaking time, and maximum velocity. The inundation mapping is prepared for the 1,000-year no-breach and dam breached scenarios. The maps also show the 100-year no-breach inundation flood boundary.

7.4 Dam Elevation and Freeboard

As required by CDA 2007 Guidelines, freeboard for dams is assessed for two different conditions as outlined below.

- ***Normal Freeboard***: No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1:1,000 year when the water level in the pond is at its maximum normal operating elevation.

- ***Minimum Freeboard***: No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1:10 year (for Significant Consequence dams) when the pond is at its maximum level during the passage of the IDF.

Figure 7.1 presents a sketch showing the normal and minimum available freeboard without waves for Bear River Dam. The normal freeboard available is the difference between the dam crest elevation, which is 655 m, and the Full Supply Level (FSL), which is 652.58 m, providing a 2.42 m normal freeboard. The minimum freeboard available for the dam is the difference between the dam crest (655.00 m) and the IDF elevation, which is 654.65 m, providing a 0.35 m freeboard.

Wind wave analysis of wave run-up and wind set-up for the Bear River Reservoir was conducted using procedures outlined in the Bureau of Reclamation Design Standards No 13: Embankment Dams (2012), (see Appendix V). As per the frequency analysis conducted on the maximum daily wind speed at Grande Prairie Airport station, the maximum wind speeds are expected to come from the West and Northwest. The fetch for both directions were estimated and the wind set-up, wave run-up, and total wind effects for the reservoir were estimated.

Available freeboard estimated based on wave run-up elevations for normal and minimum conditions are summarized in **Table 7.2**. While the IDF can be routed through the spillway without causing an overtopping of the structure, the available (minimum) freeboard of 0.35 m is not sufficient to avoid wave overtopping under a 1:10-year wind. An additional 0.28 m additional freeboard is necessary to avoid overtopping by 95% of waves generated during this critical scenario, for a total of 0.63 m. The normal freeboard for the reservoir at FSL is adequate.

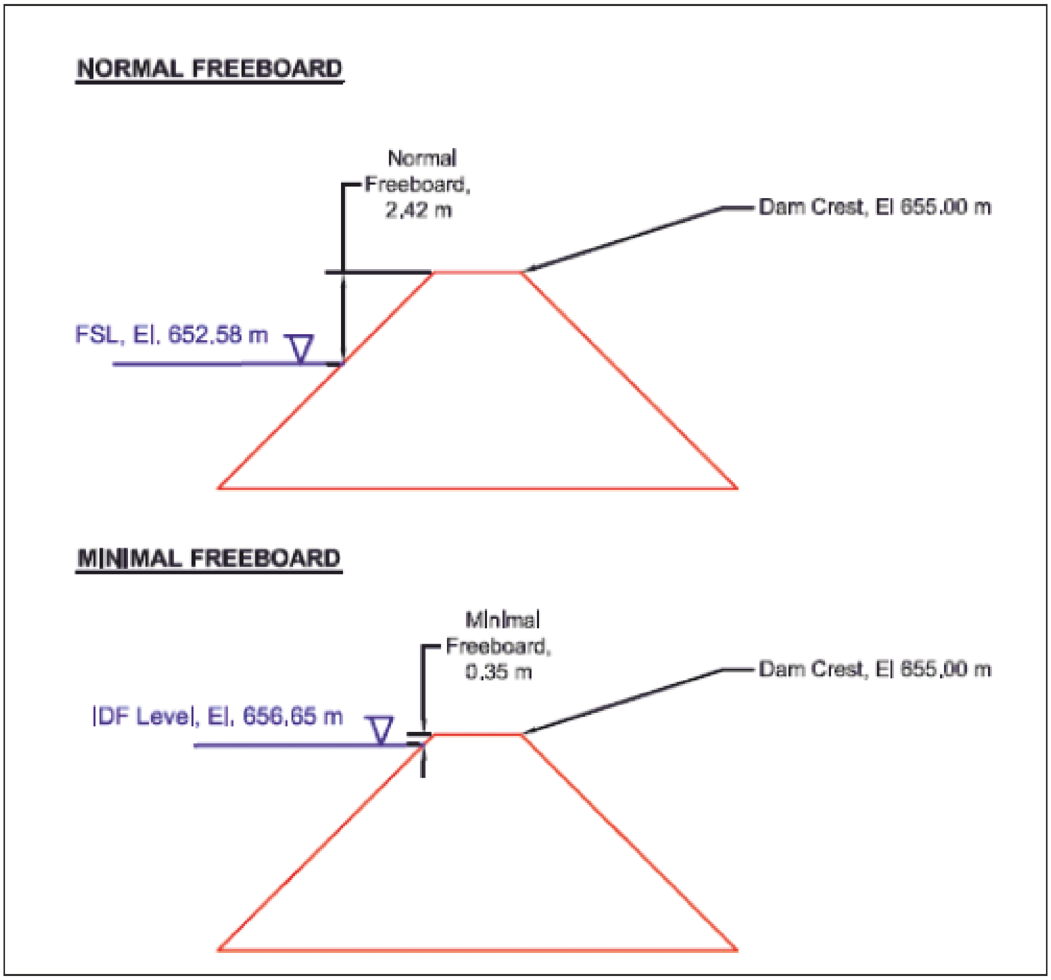


Figure 7.1 Normal and Minimum Freeboard

Table 7.2 Summary of Estimated Run-up during Minimum and Normal Freeboard for Lowest Berm Elevation of 655 masl

Wind Direction	Freeboard Condition	FSL/IDF Elevation (masl)	Wind Return Period (years)	Total Wind and Wave Effects (Required Freeboard) (m)	Available Freeboard (m)
West Wind	Normal Freeboard	652.58[1]	1,000	0.74	2.42
	Minimum Freeboard (1:500-year flood)	654.65	10	0.50	0.35
Northwest Wind	Normal Freeboard	652.58[1]	1,000	0.83	2.42
	Minimum Freeboard (1:500-year flood)	654.65	10	0.63	0.35

[1] Full Supply Level (FSL)

7.5 Control Structure Operation and Zone of Influence

The Bear River gates are operated mainly for recreation and to moderate the flood flows in the reservoir. It is understood that currently there is no formal operation rule for the reservoir.

The spillway gates characteristics are presented in **Table 2.1**. The spillway capacity was determined using equations from the technical reference manual "Design of Small Dams", from the United States Bureau of Reclamation (USBR, 1987).

When the upstream water level is lower than the radial gate lower lip, there is a free flowing weir, and the capacity is determined using the equation below:

$$Qweir = C\sqrt{2g}\,L\,H^{3/2}$$

With C: Discharge coefficient (0.36 for the free weir flow)
H: Head above sill (m)
L: total efficient gate width (see below) (m)

$$L = L' - 2(nK_{pier} + K_{abutment})H$$

With L': Total gross gate width (m)
K_{pier}: Pier head loss coefficient (0.01)
$K_{abutment}$: Abutment head loss coefficient (0.1)

The capacity when the radial gate is submerged is determined using the equation below:

$$Qradial = C\,D\,L'\sqrt{2gh}$$

With C: Discharge coefficient (0.70 for submerged flow)
h: Head above middle of vertical opening (m)
D: Gate opening (m)

The resulting total capacity curve of the spillway is shown in **Figure 7.2**.

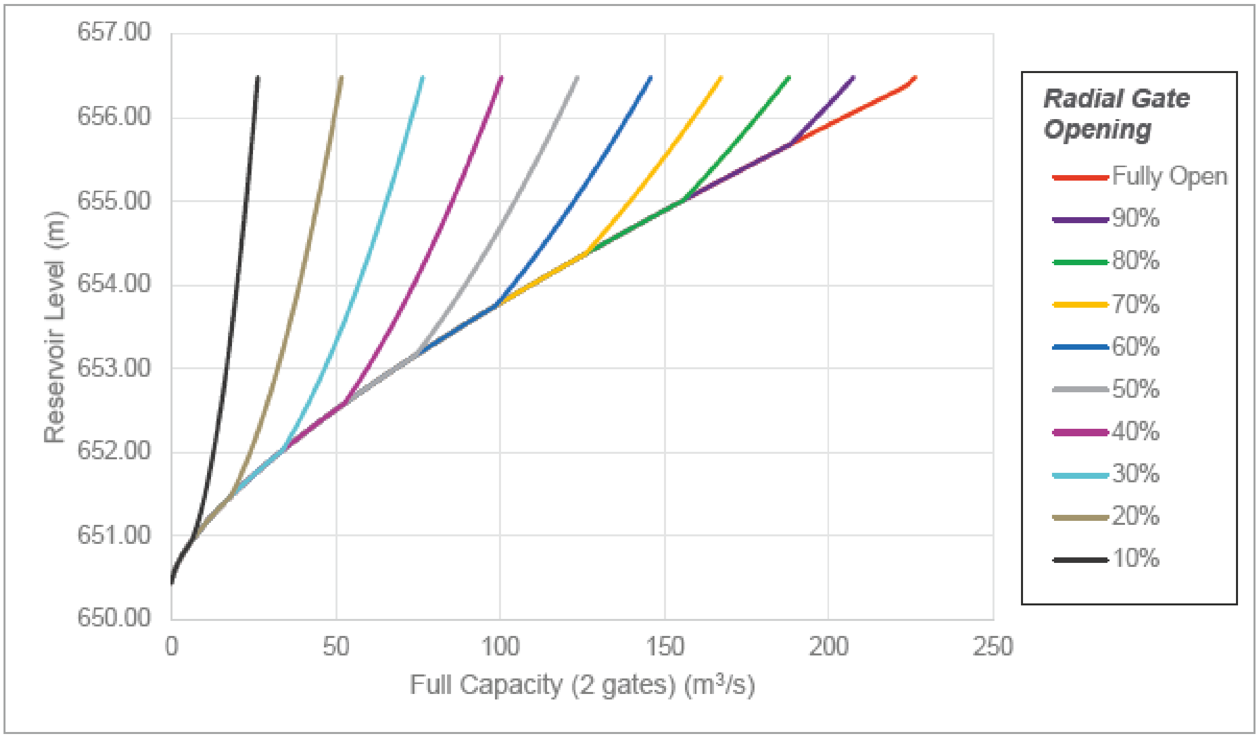


Figure 7.2 Total Spillway Capacity

Discussion with the gate operator during the site inspection indicated that the current normal operating procedure of the gates during spring flood events is to maintain 30% opening and gradually decrease the opening to close to 5%. For the current study, simulation of the reservoir routing for the various flood return periods and gate openings is conducted to understand the overall behaviour of the reservoir.

The following summarizes the 30% and 50% gate openings and the available freeboards. It is assumed that the gate opening will be the same for both gates.

Gate Opening – 30%

- The 1:2-year flow at 652.00 m reservoir elevation provides a 3.00 m freeboard.
- The 1:5-year flow at 652.85 m reservoir elevation provides a 2.15 m freeboard.
- The 1:10-year flow at 653.76 m reservoir elevation provides a 1.24 m freeboard.
- The 1:50-year flow at 655.14 m reservoir elevation overtops the dam.

Gate Opening – 50%

- The 1:5-year flow at 652.37 m reservoir elevation provides a 2.63 m freeboard.
- The 1:10-year flow at 652.65 m reservoir elevation provides a 2.35 m freeboard.
- The 1:50-year flow at 653.64 m reservoir elevation provides a 1.36 m freeboard.
- The 100-year flow at 654.50 m reservoir elevation will provide only a 0.50 m freeboard.

Full Gate Opening

- Floods with a 2-year to 100-year return period can pass through the open gate with adequate freeboard.
- The 1:500-year flood is routed with a maximum reservoir elevation of 654.65 m elevation, providing an insufficient freeboard of 0.35 m (see **Section 7.4**).
- The 1:1000-year flow at 655.04 m reservoir elevation overtops the dam.

7.5.1 Proposed Gate Operation

It is understood that the flood events are not monitored at the inlet to the reservoir and it will be difficult for the gate operator to estimate the incoming flow. Based on the above simulation results of the various gate openings, the following simple, but conservative gate operation rules are recommended for the Bear River Control Structure during spring flood events:

- Open gates at 30% until reservoir elevation exceeds 652.80 m;
- Open gates at 50% until reservoir elevation exceeds 654.00 m; and
- Open gates fully above reservoir elevation 654.00 m.

Figure 7.3 shows the gate operation scheme. **Figure 7.4** shows an example of the application of the gate operation scheme to the routing of the 1:500-year flood. The operation scheme leads to the same maximum elevation as a constant full gate opening and can therefore be used to safely route the IDF.

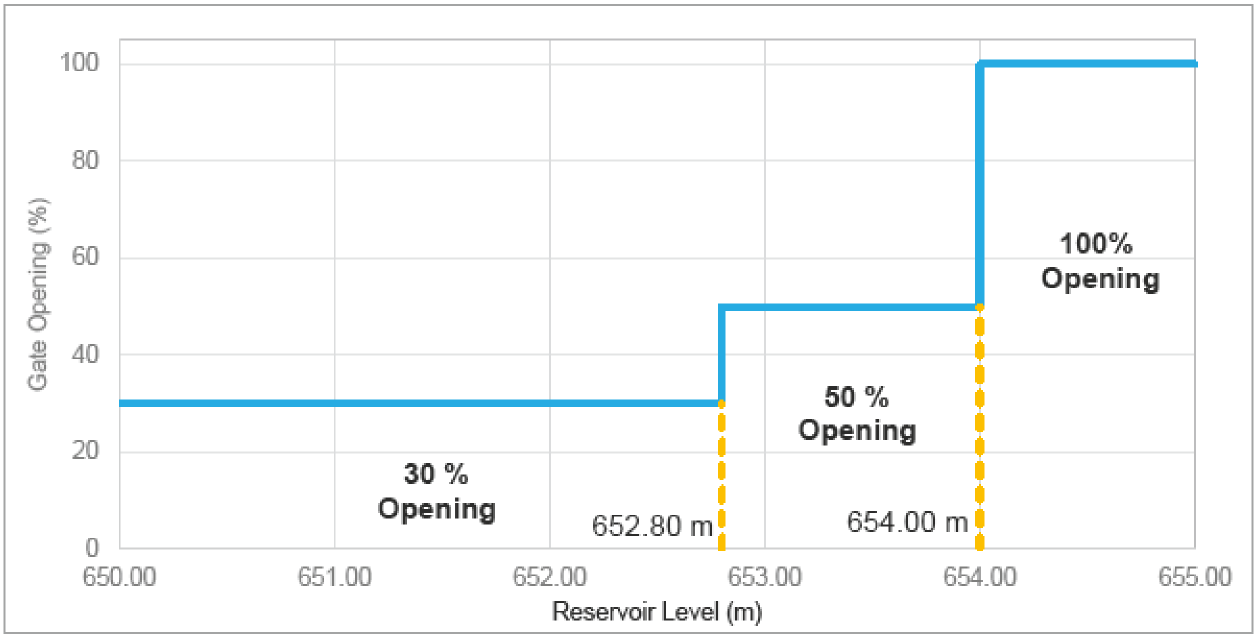


Figure 7.3 Gate Operation Scheme

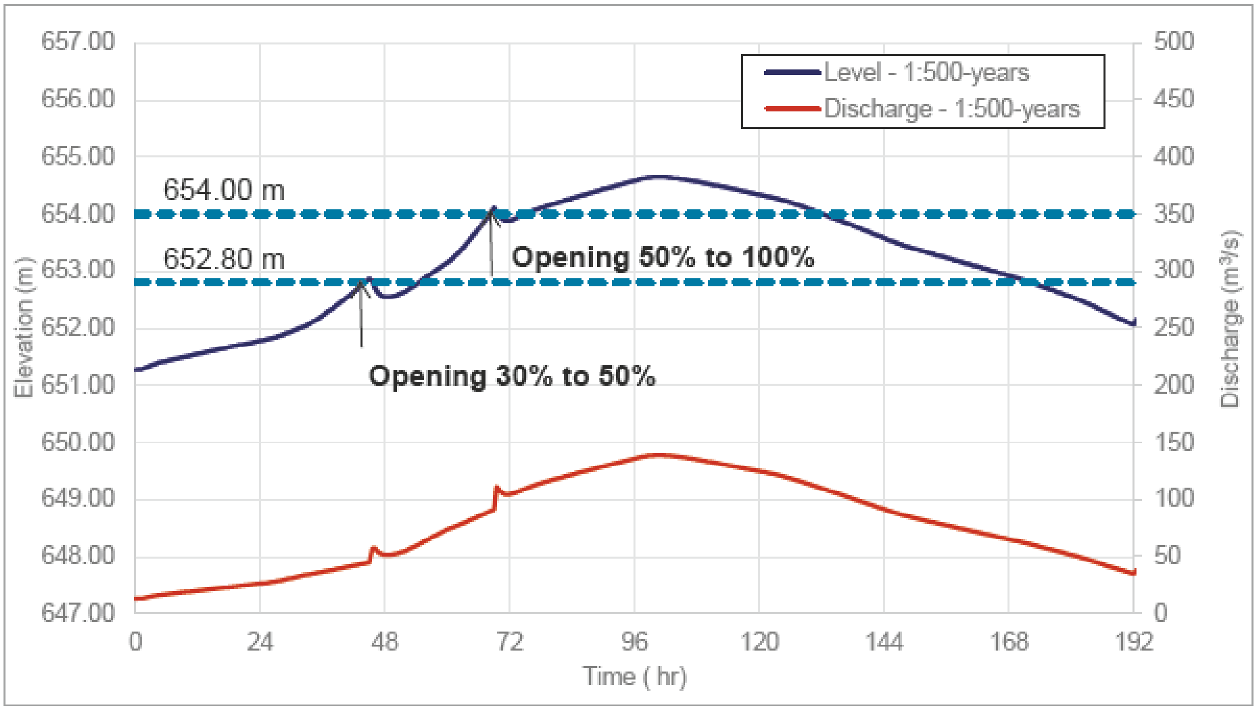


Figure 7.4 Gate Operation applied to the 1:500-year Flood Routing Control Structure Zone of Influence

As presented in **Figure 7.5**, under low flow conditions (<5-year flood), the zone of influence extend about 800 m upstream of the Bear River Control Structure, downstream of the 108 Street Bridge. Therefore, for these flow values, the operation of the gates will not have any influence on the Bear River flow surface water upstream of the 108 Street Bridge.

For higher flow conditions, the zone of influence can reach up to 3 km upstream of the Bear River Control Structure.

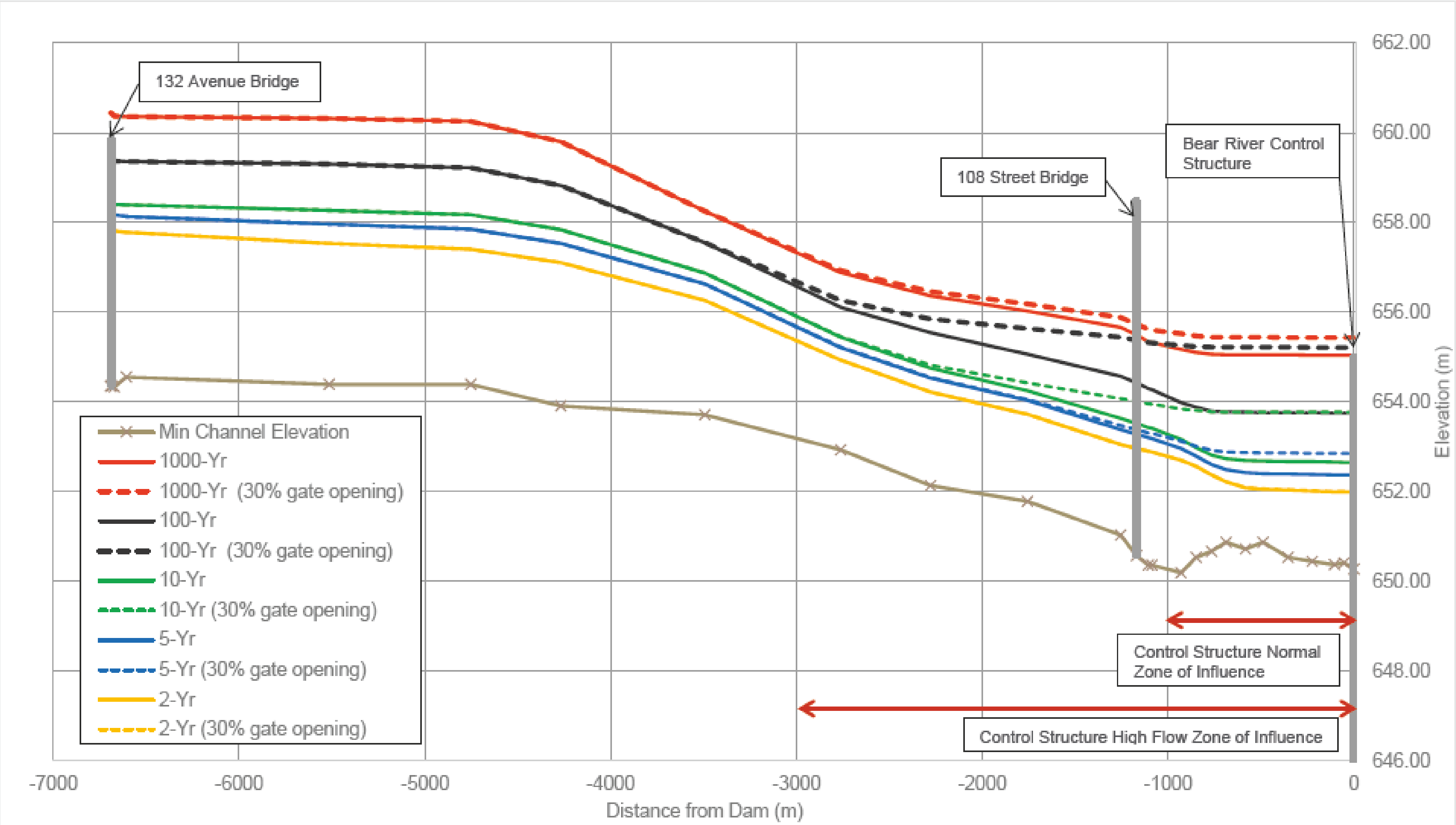


Figure 7.5 Bear River Upstream Water Surface Profile

7.6 Bypass Infrastructure Installation Priority

After reviewing the consequence classification, the IDF for the Bear River Dam is proposed to be the 500-year flood event. The spillway has sufficient capacity to route the IDF, and there is therefore no need for an additional bypass structure.

However, the available freeboard (0.35 m) is insufficient to resist overtopping from the wave action, and options to increase the available freeboard to the required 0.63 m, such as a rise of the crest elevation, should be explored.

8 Geotechnical Analysis

8.1 General

The geotechnical review for DSR generally includes a comprehensive review of the dam slope stability, instrumentation and monitoring system, liquefaction potential, etc. in compliance with the CDA DSG guidelines and other applicable best practices. This section describes geotechnical analyses completed for the Bear River Dam based on the available information.

8.2 Instrumentation Review

There is currently no instrumentation installed at the Bear River Dam.

8.3 Geotechnical Setting

8.3.1 Geology

Based on available Alberta Geological Survey (AGS) surficial geology maps, the Bear River facility is located on Pleistocene glaciolacustrine deposits. Previous reviews of 1975 borehole data and test logs indicate that the dam is constructed on an approximately 14 m thick layer of stiff to hard clayey till, which is underlain by 1.5 m of stiff clay (Golder 2014).

8.4 Slope Stability Analysis

8.4.1 Methodology

The Slope/W package Geostudio 2021 (version 11.0.1.21429) by Geoslope International was used to conduct the slope stability and seepage analyses and to estimate factors of safety. The method of analysis used for this study was the Morgenstern-Price method for a 2D limit equilibrium model.

Slope stability analysis was carried out for selected sections of the Bear River Dam to calculate Factor of Safety (FoS) and to check the conformance with the CDA (2013). The FoS criteria for dams according to the CDA (2013) for static and seismic loading conditions are shown in **Table 8.1** and **Table 8.2**.

Table 8.1 Factors of Safety criteria for Slope Stability – Static Assessment (construction, operation, and transition phase)

Loading Condition	Minimum Factor of Safety (1)	Slope
End of construction before reservoir filling	1.3	Upstream and downstream
Long term (steady state seepage, normal reservoir level)	1.5	Downstream
Full or partial rapid drawdown	1.2-1.3(2)	Upstream

Note (1) Factor of Safety is the factor required to reduce operational shear strength parameters to bring a potential sliding mass into a state of limiting equilibrium, using generally accepted methods of analysis.

Note (2) Higher factors of safety may be required if drawdown occurs relatively frequently during normal operation.

Table 8.2 Factors of Safety criteria for Slope Stability – Seismic Assessment (construction, operation, and transition phase)

Loading Condition	Minimum Factor of Safety (1)	Slope
Pseudo-static	1.0	Upstream and downstream
Post-earthquake(2)	1.2-1.3	Upstream and downstream

Note (1) Factor of Safety is the factor required to reduce operational shear strength parameters to bring a potential sliding mass into a state of limiting equilibrium, using generally accepted methods of analysis.

Note (2) Post-earthquake stability indicates that movements from an earthquake have moved and "remolded" the dyke material, which would change its strength properties. This is only checked if the dam has a FOS <1 in a Pseudo-static analysis.

The following loading cases were analyzed and the factor of safety for each calculated:

- static stability of the downstream slope at FSL;
- static stability of the downstream slope at IDF level;
- rapid drawdown of the upstream slope; and
- pseudo-static seismic stability of the downstream slope at FSL.

8.4.2 Surface and Subsurface Geometry

The surface geometry of the models was based on the results of the GPS survey of the dam conducted by GeoVerra on October 15, 2020. The subsurface geometry of the dam is adapted from the 2013 DSR report, which used previous boreholes and test logs that show stiff to hard clayey till to approximately 14 m below ground surface (bgs), underlain by stiff clay (Golder 2014). The 0.3 m thick upstream slope riprap layer was also added to the model for this analysis.

Three typical cross-sections were selected for the main dam based on the geometry and geology and were considered to represent critical sections for stability assessment purposes. The selected cross-sections were designated as A-A', B-B', and C-C' and are shown on Drawing 3 and Drawing 4. The same cross-sections were used in the Seep/W modelling.

8.4.3 Material Parameters

SNC-Lavalin reviewed the material properties used in the previous DSR, which were based on typical literature values attributed to the fill materials and foundation soils (Golder 2014). The material properties used by Golder are presented in **Table 8.3**.

Table 8.3 2013 DSR Material Properties

Material	Wet Density, γ (kN/m^3)	Effective Friction Angle, φ, (°)	Effective Cohesion, c', (kPa)
Embankment Fill	19.0	23	10
Clay Till	20.0	30	0

In SNC-Lavalin's opinion, the inclusion of a cohesion parameter for the embankment fill is not appropriate. The embankment fill cohesion parameter may have been used in previous modelling, as previous versions of the Slope/W program did not allow the user to specify a minimum slip surface depth, which often resulted in the lowest factor of safety calculated by the model being a thin surficial failure which was not significant. Engineers would commonly correct for this issue by including a small cohesion parameter in the surface soil layer. As more recent versions of Slope/W allow a minimum slip surface depth to be specified, this correction is not necessary. Based on previous experience at similar sites, the friction angle of the embankment fill was increased from 23° to 28°. Generally, the fill material has no cohesion in the design while the source material, the clay till in situ, would have a c' (effective cohesion). This is reasonable, as the in-situ material has experienced a hundred thousand years of pressure from more than a kilometer of ice. Once excavated and replaced as fill material, the original strength is not regained, no matter how well compacted by man or machine.

In our analysis, the material properties used for the stability analysis are presented in **Table 8.4**.

Table 8.4 Material Properties Used for Slope Stability Analysis

Material	Wet Density, γ (kN/m^3)	Effective Friction Angle, φ, (°)	Effective Cohesion, c', (kPa)
Embankment Fill	19.0	28	0
Clay Till	20.0	30	10
Riprap	22.0	40	0

8.4.4 Phreatic Surface

Steady state seepage through the selected section was modelled using a two-dimensional numerical modelling program Seep/W. Seepage modelling was carried out to identify the phreatic surface at steady state FSL and the IDF level (steady state). The phreatic surfaces are modelled as steady state conditions for FSL and IDF although the levels may change with time due to reservoir level variation and environmental factors such as groundwater conditions and precipitation.

There are no piezometers or other instrumentation installed in the dam that can directly measure the phreatic surface. The installation of two nested pairs of vibrating wire piezometers in the dam, with piezometer tips set in both the dam fill material and foundation material, would improve the knowledge of the phreatic surface in the dam and reduce risk.

8.4.5 Seismic Condition

In accordance with the classification system recommended in the CDA (2013) Dam Safety Guidelines, Bear River should be considered as a Significant consequence structure. Considering the classification as a Significant consequence structure, appropriate design criteria for evaluating the safety of the dam should be the Earthquake Design Ground Motion for an Annual Exceedance Probability of 1-in-1,000-year return period.

According to 2015 National Building Code Seismic Hazard Calculation, the peak ground acceleration (PGA) in the Bear River area for a 1-in-1,000-year return period is 0.042 g.

A horizontal force (seismic coefficient) was applied to the failure mass which is proportional to the design horizontal acceleration for the analysis of seismic condition. One-half the PGA (0.5PGA) (Hynes-Griffin and Franklin 1984) was used for the non-rigid response of the dam embankment and foundation. As recommended by CDA (2013) Guideline Bulletins, the vertical component of the earthquake was not employed in the stability analyses.

8.4.6 Slope Stability Analysis Results

A summary of the calculated FoS for Sections A-A', B-B', and C-C' are provided in **Table 8.5** and figures of the slope stability models are included in Appendix VI.

The FoS for main dam was analyzed for the FSL, IDF, and RDD cases for static loading condition. The calculated FoS under seismic loading based on the pseudo-static analyses also meets the minimum requirements as per CDA (2013). Slip surfaces that are less than 1 m depth below the surface are not considered significant and are not reported.

Table 8.5 Modelling Results Summary

Dam Section	Loading Conditions	Reservoir Elevation (m)	Factor of Safety[1]			Appendix Figure No.
			Upstream	Downstream	Seismic event at FSL (with 1/2 PGA)	
A-A'	FSL	652.58	-	3.4	2.9	VI-01 / VI-02
	IDF	654.65	-	2.5	-	VI-03
	RDD	650.58	1.2	-	-	VI-04
B-B'	FSL	652.58	-	3.3	2.8	VI-05 / VI-06
	IDF	654.65	-	2.7	-	VI-07
	RDD	650.58	1.2	-	-	VI-08
C-C'	FSL	652.58	-	2.8	2.5	VI-09 / VI-10
	IDF	654.65	-	2.6	-	VI-11
	RDD	650.58	1.4	-	-	VI-12

[1] FOS that are less than minimum CDA (2013) recommended criteria are shown in **bold** face and underlined.

Based on the analysis conducted of Sections A-A', B-B', and C-C', the FoS for the dam are adequate and exceed the CDA (2013) recommended criteria.

It should be noted that the downstream FoS are higher than those calculated by Golder during the 2013 DSR. That is likely due to Golder's FoS calculations being based off of assumed upstream and downstream dam slopes (3H:1V and 4H:1V, respectively). SNC-Lavalin's FoS calculations utilized results of the topographic survey of the dam, which showed that the downstream slope of the dam is shallower, at 6H:1V or 7H:1V.

8.5 Liquefaction Assessment

A dam foundation may liquefy under specific static loading changes (such as a dyke raise), or dynamic loading (cyclic loading) (such as earthquake motion) conditions. Generally, two key characteristics of the fine-grained soil that could lead to liquefaction are the material's void ratio (which is associated with its compaction) and degree of saturation. Loose and saturated deposits are more prone to liquefaction than dense deposits.

The Bear River Dam was constructed of compacted impervious fill and is not expected to be susceptible to liquefaction. As the foundation material is known to be stiff to hard clayey till, the foundation is also not expected to be susceptible to liquefaction.

The sediment collecting in the reservoir is likely to be a high proportion of silt and may be susceptible to liquefaction. In a scenario where the reservoir silt does liquefy, it would likely result in silt being deposited against the upstream slope of the dam. The additional loading on the dam upstream slope would not be expected to be a dam safety hazard.

8.6 Geotechnical Conclusions

The geotechnical structure of the dam is in acceptable condition. SNC-Lavalin did not identify deficiencies, critical or otherwise, in our analysis or observations.

9 Structural Analysis

9.1 Sliding Stability Analysis of Spillway Concrete Structure

In this study, the rigid body sliding stability analysis of the spillway concrete structure was conducted.

The Full Supply Level remains unchanged at 652.58 m and inundation study result gives the 1:500-year flood as corresponding to a water elevation of 654.65 m.

The concrete structure stability is performed using the rigid body method and is checked under the "Usual Loading", "Unusual Loading", "IDF Flood Loading", "Earthquake Loading", and "Post-Earthquake" load combinations, as described below.

The spillway concrete structure for stability analysis starts from the construction joints at both left and right upstream wing walls to the construction joint at middle height of the downstream chute. For simplification of the overall stability analysis, the left and right upstream wing walls are considered in horizontal equilibrium condition between upstream hydrostatic pressure, upstream ice load, and downstream submerged soil lateral pressure. These forces are not included in the overall stability analysis.

For stability analysis purposes, the vertical dead loads include the weight of the concrete structure, gate equipment weight, soil weight limited to the volume above the foundation slabs, as well as the weight of water above upstream invert slab.

Gate and hoist weights are taken from the Bear River Spillway Radial Gate Replacement As-Constructed Report (Sameng 2010).

The concrete volume is calculated from the 3D model. The 3D model is built based on the original concrete works spillway drawings and the new middle trunnion concrete block from 2010 spillway radial gate replacement drawings, as shown in **Figure 9.1**.

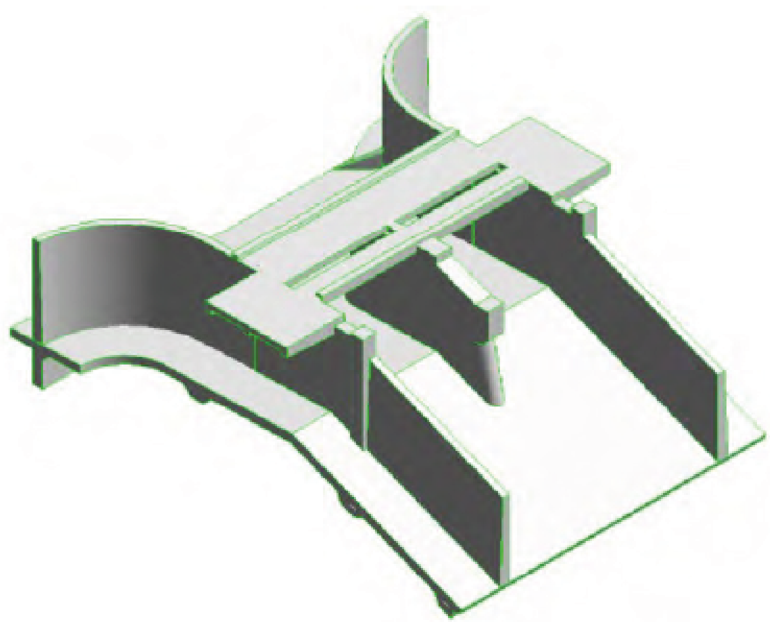


Figure 9.1 3D Model for Spillway Concrete Structure Weight Calculation

Hydrostatic loading, a linear distribution of the static water pressure acting normal to the surface of the structure is applied.

The uplift pressure is considered acting on the full contact area between the base of the structure and its foundation. Since there is no piezometer data for uplift pressure beneath the structure, simplified uplift diagrams are assumed as shown in the loading diagrams. Full uplift pressure at the upstream edge and linearly decreases to zero at the location of the construction joints at the chute where the fine filter layer was placed. No change in uplift is assumed during an earthquake event.

Hydrodynamic pressures acting on a face of a structure during an earthquake shall be determined by Zangar formula for both Usual and IDF levels, respectively.

Ice loads of 100 kN/m for Usual loading and 150kN/m for Unusual loading are considered, respectively. It is assumed that the ice cover would either be broken up or would not have an unfavourable impact. Therefore, it is not considered necessary to combine ice loads with the extreme IDF, earthquake event, and post earthquake.

According to the 2015 National Building Code Seismic Hazard Calculation, the peak ground acceleration (PGA) in the Bear River area for a 1-in-1,000-year return period is 0.042 g. One-half the PGA (0.5 PGA) is used for the pseudo-static analyses. As recommended by CDA (2013) Guideline Bulletins, the vertical component of the earthquake was not employed in the stability analyses. The earthquake load case is used to establish post-earthquake condition.

The following load cases were considered in the analysis.

Load Case: Usual – Full Supply Level EL 652.58 m (Figure 9.2)

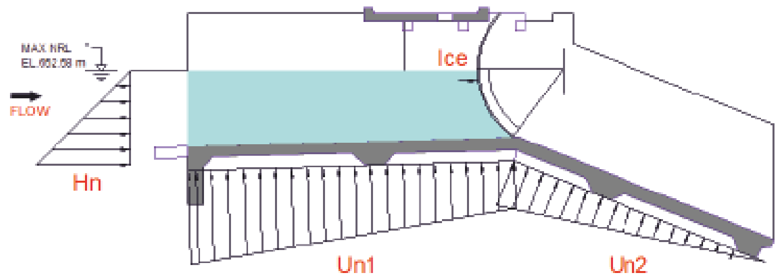
Loads experienced during usual:

- Dead loads: Concrete weight, gates weight, soil weight, water weight;
- Hydrostatic load;
- Usual ice load = 100 kN/m; and
- Uplift load.

Load Case: Unusual – Full Supply Level EL 652.58 m (Figure 9.2)

Loads experienced during unusual:

- Dead loads: Concrete weight, gates weight, soil weight, water weight;
- Hydrostatic load;
- Unusual Ice load = 150 kN/m; and
- Uplift load.



Load Case - Usual (Ice Load = 100KN/m)

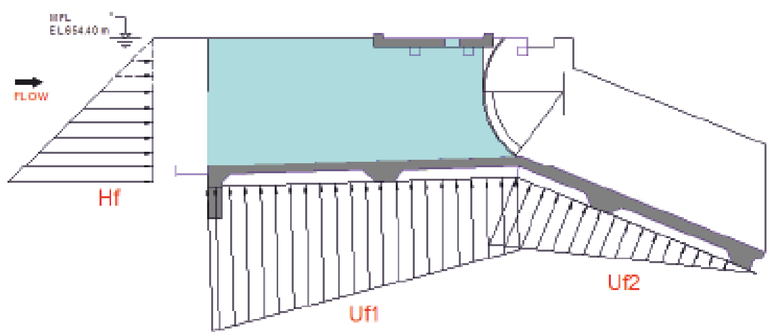
Load Case - Unusual (Ice Load =150KN/m)

Figure 9.2 Load Case – Usual and Unusual

Load Case: Extreme – IDF Flood EL 654.65 m

Loads experienced during the IDF Flood:

- Dead loads: Concrete weight, gates weight, soil weight, water weight;
- IDF flood hydrostatic load; and
- IDF uplift load.



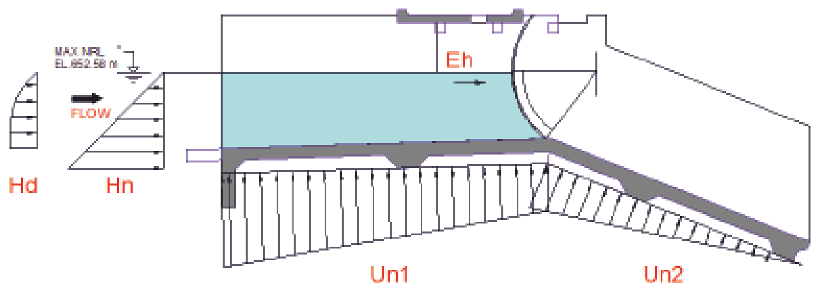
Load Case - Extreme (IDF Flood)

Figure 9.3 Load Case – Extreme (IDF Flood)

Load Case: Extreme- Earthquake – Full Supply Level EL 652.58

Loads experienced during earthquake:

- Dead loads: Concrete weight, gates weight, soil weight, water weight;
- Hydrostatic load;
- Hydrodynamic load;
- Uplift load; and
- Earthquake load, ah = 0.021 g.



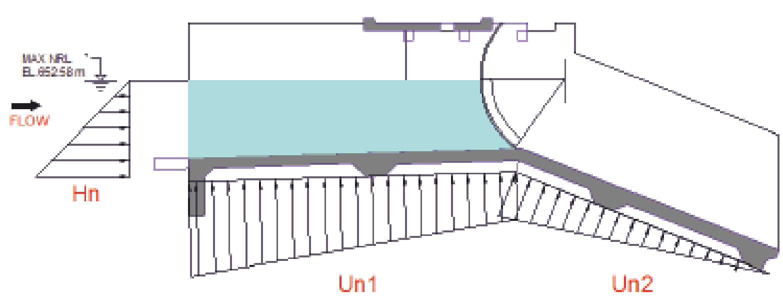
Load Case - Extreme (Earthquake)

Figure 9.4 Load Case – Extreme (Earthquake)

Load Case: post-earthquake – Full Supply Level EL 652.58

Loads experienced during post earthquake:

- Dead loads: Concrete weight, gates weight, soil weight, water weight;
- Hydrostatic load; and
- Post-earthquake uplift load.



Load Case - Post Earthquake

Figure 9.5 Load Case – Post Earthquake

The factor of safety against sliding for friction only is calculated from the following expression:

$$SF = \frac{\left(\sum N - \sum U\right)\tan\phi}{\sum H}$$

where,

ΣH	= total horizontal forces
ΣN	= total normal downward forces
ΣU	= total uplift forces
ø	= friction angle

It is assumed that the sliding plane occurs at interface between the bottom of the spillway concrete shearkey and the underlying compacted impervious backfill. The deeper but slender upstream front shearkey is disregarded.

Conservatively, the sliding stability is calculated using an interface friction angle of 30°, no cohesion is considered. The acceptance criteria as per CDA Guidelines (2007) for friction only are as follows:

- Usual: Sliding Safety Factor >1.5
- Unusual: Sliding Safety Factor >1.3
- Extreme – IDF Flood: Sliding Safety Factor >1.1
- The earthquake load case is used to establish post-earthquake condition
- Post earthquake: Sliding Safety Factor >1.1

The results of the stability analysis calculations are presented in **Table 9.1**.

Table 9.1 Structural Stability Analysis Results

Loading Case	Sliding Safety Factor Required	Sliding Safety Factor Calculated
Usual – Full Supply Level EL 652.58	1.5	2.4
Unusual – Full Supply Level EL 652.58	1.3	1.8
Extreme – IDF Flood EL 654.65	1.1	2.6
Extreme – Earthquake - Full Supply Level EL 652.58	-	4.7
Post-earthquake – Full Supply Level EL 652.58	1.1	5.5

The analyses conclude that the spillway concrete structure meets all the stability criteria set forth in the CDA Guidelines.

9.2 Middle Pier Trunnion Concrete Block - Strength Review

In the original design of radial gate trunnion support at the middle pier, the trunnion pin was placed through the pier and trunnion loads were transferred to the upstream bottom end of the pier by using an anchor block along with inclined anchors. When the gates were replaced in 2010, the arms of the new gates were slightly longer, and the trunnion location was downstream of the original location. The new trunnions were attached to the side of the pier, which was locally extended and reinforced on the downstream side. The relevant documents made available to SNC-Lavalin as part of this mandate - Bear River Spillway Radial Gate Replacement As-Constructed Report – provide some details of the pier extension/trunnion block and one drawing (from Sameng) also shows the size and reinforcement details for the new trunnion block. Design calculations or criteria used for transferring the new trunnion loads to the pier are, however, not available. The Sameng drawing shows that the new concrete block was attached to the middle pier using 4-25M and 2-15M HILTI RE500 epoxy adhesive anchor rebars with embedment depth of 500 mm, as shown in **Figure 9.6**.

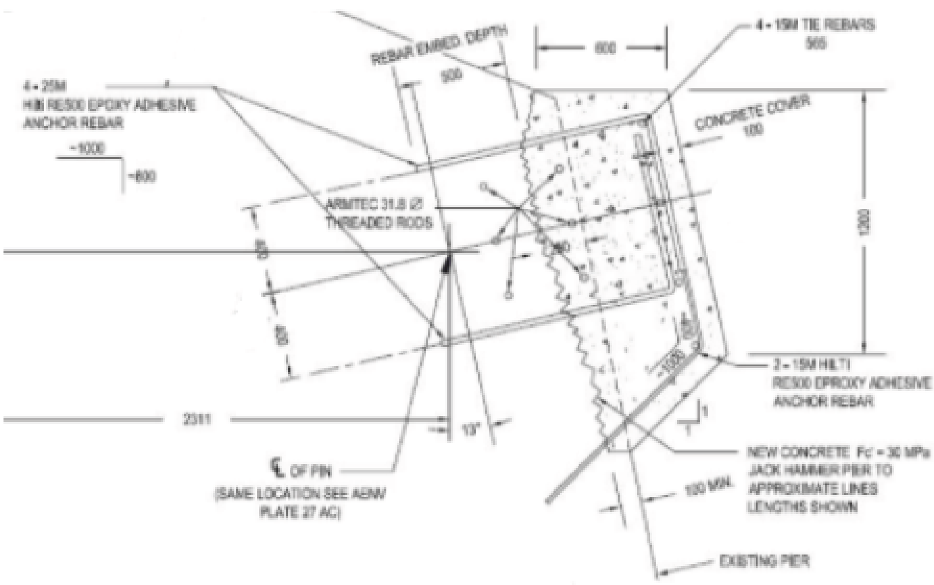


Figure 9.6 Middle Trunnion Concrete Block (Sameng 2010)

As part of the present scope, strength of this middle trunnion block is assessed for two load cases:

1. For hydrostatic load corresponding to the new IDF flood level of 654.65 m; and,
2. For the normal gate operation in winter when the gates are kept at 30% open position and are subject to ice loading.

Using the available information, factored resistance of the new concrete block (governed by concrete breakout resistance) is found to be 460 kN.

9.2.1 IDF Loading

For the IDF loading (hydrostatic load on the gate corresponding to IDF level of 654.65m, with no load factor), the trunnion force is found to be 361kN, which is lower than the resistance of the trunnion block. The new block is thus safe for this loading.

9.2.2 Ice Loading

With respect to the trunnion resistance for ice loading on the gates, it is noted that the gates are kept partially open during winter months, with the reservoir drawn down. Information on water level during winter months is not known, but with the gates at 30% open position the water level is expected to be lower than the normal reservoir level. Moreover, with such an operation of the gate, it is difficult to predict/assess ice loading that will act on the gate, particularly when no long-term site-specific measurements are available. In view of the above, we have used the following approach to assess ice loading on the gate.

The approach is based on a 2003 research report by CEATI (which is also referenced by CDA) which notes that ice loads can vary significantly from site to site and provides a model to assess ice loading ("CEATI Ice Load Model") at a given site. For a given far-field ice loading, the site-specific ice load on a spillway gate/trunnion is shown to vary depending on the span and rigidity of the gate ("bridging" effect), as well as on fluctuation of water level during winters. Although this model is developed based on data gathered from dam sites in eastern Canada, it can be used for ice load determination in similar weather conditions in other similar regions of Canada. Using this model, for a thermally induced far-field ice load of 150 kN/m (a commonly used value), the ice load on Bear River spillway gates come out to be 56 kN/m after accounting for the bridging effect. The effect of water level fluctuations could not be assessed as relevant data is not available. It may be noted that long-term site-specific data related to water level fluctuations and ice thickness etc. would be required for more precise analysis to determine the site-specific ice loading on the Bear River radial gates which is out of scope of this review work.

Using the above estimated ice load (56 kN/m) and a hydrostatic load corresponding to 1.47 m of hydrostatic head on the gate (30% gate opening), the unfactored trunnion load on the middle pier comes out to 365kN. Considering a load factor of 1.25 for unusual case, the factored trunnion load for this load case would be 459.2 kN, which is within the factored resistance of the new concrete block at the middle pier.

9.3 Conclusions

The new concrete block at the trunnion location on the middle pier has adequate strength to support trunnion loads corresponding to the new IDF load case. With respect to the ice loading, the resistance of this block appears to be adequate for an ice load of 56 kN/m (as assessed using the "bridging" effect in the CEATI Ice Load Model) with the gates at 30% open position.

Site specific measurement of the ice load is recommended for a few years to assess/confirm whether the loading considered here is representative. In case higher ice loads are predicted, the trunnion block would require strengthening.

10 Dam Safety Management

A component of this project was assisting the City in development of their Dam Safety Management System (DSMS) by creating an Operations, Maintenance, and Surveillance Manual (OMS), Emergency Preparedness Plan (EPP), and Emergency Response Plan (ERP) for Bear River. **Table 10.1** provides a summary of the Bear River dam safety document management.

Table 10.1 Bear River Dam Safety Document Management

Item	Current/Active	Proposed Revision	Review Frequency
Inundation Study	2020	--	--
EPP	2020	2021	Annual
ERP	2020	2021	Annual
OMS	2020	2021	Annual
DSR	2020	2030	Every 10 years

11 Recommendations

SNC-Lavalin completed the detailed review of the available information for the Bear River dam and associated structures. SNC-Lavalin did not identify any high priority concerns. Eleven concerns of low to medium priority were identified and are presented in **Table 11.1**. In general, eight areas of improvement were identified that should be addressed through ongoing maintenance, management, and monitoring, as presented in **Table 11.1**.

Table 11.1 Finding Summary from the 2020 DSR

Item Number	Finding	Priority Rating[1]	Report Section	Recommendations
2020-01	There are a number of trees and bushes growing on the upstream slopes, crest, and downstream slopes of the dam.	Low	Section 4.2.1	The trees (particularly the large and all deciduous trees) and bushes on the dam should be removed at some point in the next few years.
2020-02	There is a bush growing within the fenced access at the top of the spillway that prevents immediate access to the northern gate and its mechanism.	Maintenance	Section 4.2.4	We recommend that the vegetation be removed or trimmed to prevent obstruction (noted to have been removed during 2021 spillway inspection).
2020-03	Depressions were observed on the north side of the downstream slope of the dam. This may be the location of the original spillway.	Monitoring	Section 4.2.1	Monitor this area for any changes, water seepage, or further movement.
2020-04	Erosion channels are developing above the riprap along the spillway downstream wing walls.	Low	Section 4.2.5	The erosion should be repaired, and the riprap armouring should be extended higher up the channel bank along the spillway wing walls to prevent further erosion.
2020-05	The spillway approach boom was not in place.	Maintenance	Section 0	The boom should be reinstated, and a planned maintenance occur to remove debris from the boom following storm events.
2020-06	The reservoir is filled with sediment.	Low	Section 0	The capacity of the dead storage of the reservoir is almost lost to sediment transported from upstream. Monitoring of sediment deposit will be required to assess the impact on the loss of live storage of the reservoir. Dredging of sediment might be required accordingly.
2020-07	Two large cracks were observed in the concrete spillway that expose rebar.	Low	Section 4.2.3	Cracks that expose rebar should be repaired to minimize corrosion risk and maintain dam integrity and prolong the structure's life.
2020-08	There are bushes and tree branches accumulated on top of the gates and horizontal girders. Tree branch was caught on the south arm of the south gate as well. Minor damages have been shown on the J seal from the debris accumulating on top of the gates.	Medium	Section 4.2.4	The affected areas on the gates should be cleared from branches and debris.
2020-09	Debris was seen wedged or hanged between the cables and skin plate.	Low	Section 4.2.4	The condition of the connection points between the cables and skin plates at the bottom of the gates shall be checked regularly for damage or corrosion and any debris or branches shall be removed.

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Table 11.1 (Cont'd) Finding Summary from the 2020 DSR

Item Number	Finding	Priority Rating[1]	Report Section	Recommendations
2020-10	Corrosion is forming on the gate hoisting equipment. Cable drums and pulleys were showing light corrosions at the contact points with the cables. The block bearings, couplings, and drive shafts show minor corrosions.	Low	Section 4.2.4	Recommended that the equipment be painted to prevent corrosion.
2020-11	The hoist hand wheels do not have any lock-out devices.	Maintenance	Section 4.2.4	Recommend removal or lock-out of the hoist hand wheels to prevent unauthorized operation of the gates.
2020-12	There is no preventative maintenance program for the gates and hoisting equipment. Since 2009, there has been no maintenance performed on the equipment.	Maintenance	Section 4.2.4	A maintenance program should be developed.
2020-13	The sensor on the south gate actuator indicating overheating is faulty.	Maintenance	Section 4.2.4	The sensor should be corrected.
2020-14	The bottom seal on the north gate is damaged in the centre resulting in leakage under the gate when fully closed.	Low	Section 4.2.4	The seal should be replaced.
2020-15	Electrical cabinet grounding cable is disconnected from grounding rod and bond connection to fence is not sufficient to provide adequate grounding.	Maintenance	Section 4.2.4	Reinstate grounding connection.
2020-16	The minimal freeboard available while routing the IDF (0.35 m) is insufficient and need to be increased to 0.63 m.	Medium	Section 7.4	Recommended to study options to increase the available freeboard, such a raising of the dam crest or providing a flashboard barrier for wave action and runup.
2020-17	The added concrete block which supports the middle trunnions seems not to have adequate strength against the ice load with the gates at less than 30% opening.	Medium	Section 9.2.2	Review of the original design calculations is required. Detailed analysis of the strength of the added middle concrete block against the ice loads on the gates should be performed. The current operating procedures and 30% winter gate opening should be reviewed.
2020-18	Site specific ice loading on the radial gates due to reservoir water fluctuation should be checked.	Low	Section 9.2.2	Site specific measurement of the ice load is recommended for a few years to assess/confirm whether the loading considered here is representative. In case higher ice loads are predicted, the trunnion block would require strengthening.

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Table 11.1 (Cont'd) Finding Summary from the 2020 DSR

Item Number	Finding	Priority Rating[1]	Report Section	Recommendations
2020-19	There are only two danger signs located on either side of the spillway along the access path for public warning and notification.	Maintenance	--	Recommended to install warning signs at public access points to the reservoir, upstream of the dam, and along the pathway access points to the northeast/southwest of the dam.

[1]Priority Rating

High:	A high probability or actual dam safety issue considered immediately dangerous to life, health, or the environment, or a significant risk of regulatory enforcement.
Medium:	If not corrected, could likely result in dam safety issues leading to injury, environmental impact, or significant regulatory enforcement; or, a repetitive deficiency that demonstrates a systematic breakdown of procedures.
Low:	Single occurrences of deficiencies or non-conformances that alone would not be expected to result in dam safety issues.
Maintenance/Monitoring:	Further improvements are necessary to meet industry best practice or reduce potential risks.

12 Closure

The sections of this report were prepared by the signatories listed below. Chris Duncan is sealing for geotechnical advice and recommendations. Daniel Damov is sealing for hydrotechnical advice and recommendations. Arif Kartawidjaja is sealing for structural advice and recommendations. Maryam Nasseri is sealing for mechanical and electrical advice and recommendations. Alistair James is signing as project reviewer and responsible member. We trust that this report meets your requirements. Should you have any questions or comments, please contact SNC-Lavalin Inc. at 1.780.436.9400.

Prepared by:

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2021-07-29

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Prepared by:

17Jul2021
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Prepared by:

28-Jul-21

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Reviewed by:

Alistair James, P.Eng.
Principal Geotechnical Engineer

Geoscience & Materials
Engineering, Design and Project Management

PERMIT TO PRACTICE
SNC-LAVALIN INC. ENGINEERING, DESIGN AND PROJECT MANAGEMENT
RM SIGNATURE: ____________
RM APEGA ID #: 138459
DATE: 2021 Jul 30
PERMIT NUMBER: P009643
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

13 References

Albert Transportation (AT), 2004. Guidelines on Extreme Flood Analysis. Prepared for Transportation and Civil Engineering Division. November 2004

Canadian Dam Association (CDA), 2013. 2007 Dam Safety Guidelines. Revised 2013.

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Hynes-Griffin, M.E. and Franklin, A.G., 1984. "Rationalizing the seismic coefficient method." U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, 1984, Miscellaneous Paper GL-84-13, 21 pp.

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U.S. Bureau of Reclamation (USB$) 1987. Design of Small Dams. Third Edition, 1987.

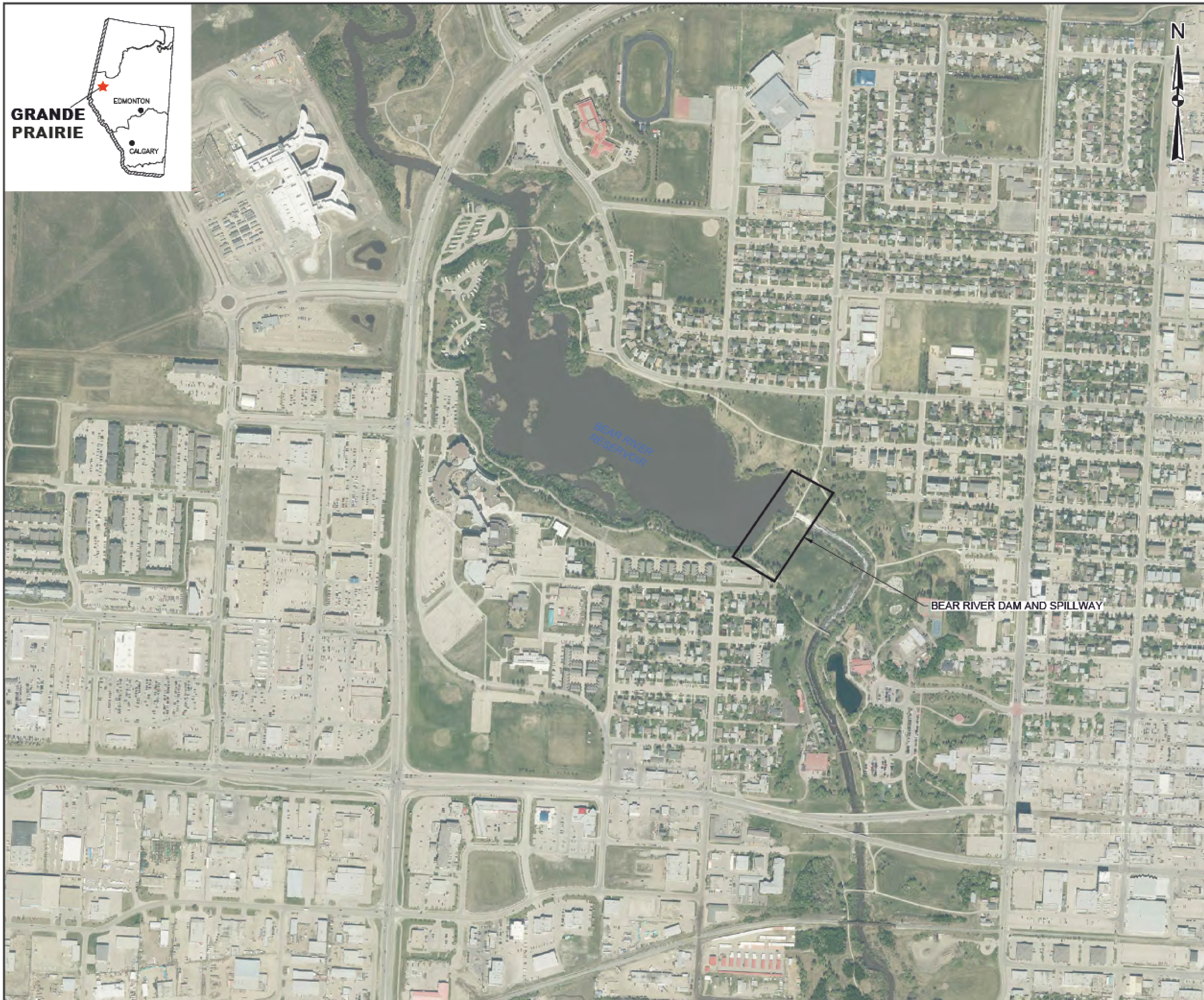
Drawings

1 Site Location Plan

2 Site Plan

3 Topographic Survey

4 Cross-Sections



LEGEND

NOTES

1. Imagery provided by client (2020).

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REFERENCE DRAWINGS

DWG No	DESCRIPTION

REVISIONS

REV	DATE	DESCRIPTION	DES	DRN	CHK	APP
PA	2021-01-07	ISSUED FOR INFORMATION	CD	AC	CD	AJ

1:7,500 — 0 100 200 300 m

SNC·LAVALIN

CLIENT	PROJECT LOCATION
CITY OF GRANDE PRAIRIE	BEAR RIVER CONTROL STRUCTURE GRANDE PRAIRIE, ALBERTA

TITLE

SITE LOCATION PLAN

DATE	2020-10-19	DWG No	676065-0000-4EDD-1000	FIG	1	REV	PA

11X17

Date Plotted: January 7, 2021

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LEGEND

NOTES

1. Imagery provided by client (2020).

NOT FOR CONSTRUCTION

REFERENCE DRAWINGS

DWG No	DESCRIPTION

REVISIONS

REV	DATE	DESCRIPTION	DES	DRN	CHK	APP
PA	2021-01-07	ISSUED FOR INFORMATION	CD	AC	CD	AJ

1:1,000 — 0 10 20 30 40 50 m

SNC · LAVALIN

CLIENT	PROJECT LOCATION
CITY OF GRANDE PRAIRIE	BEAR RIVER CONTROL STRUCTURE GRANDE PRAIRIE, ALBERTA

TITLE

SITE PLAN

DATE 2020-10-19 | DWG No 676065-0000-4EDD-1001 | FIG 2 | REV PA

11X17

Date Plotted: January 7, 2021

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LEGEND

NOTES

1. Imagery provided by client (2020).
2. Drawings coordinates are in UTM, NAD 83 Zone 11.
3. Distances are in metres (m).
4. Elevations are in metres above sea level (masl).

NOT FOR CONSTRUCTION

REFERENCE DRAWINGS

DWG No	DESCRIPTION

REVISIONS

REV	DATE	DESCRIPTION	DES	DRN	CHK	APP
PA	2021-01-07	ISSUED FOR INFORMATION	CD	AC	CD	AJ

1:1,000 — 0 10 20 30 40 50 m

SNC·LAVALIN

CLIENT	PROJECT LOCATION
CITY OF GRANDE PRAIRIE	BEAR RIVER CONTROL STRUCTURE GRANDE PRAIRIE, ALBERTA

TITLE

TOPOGRAPHIC SURVEY

DATE	2020-10-19	DWG No	676065-0000-4EDD-1002	FIG	3	REV	PA

11X17

Date Plotted: January 7, 2021

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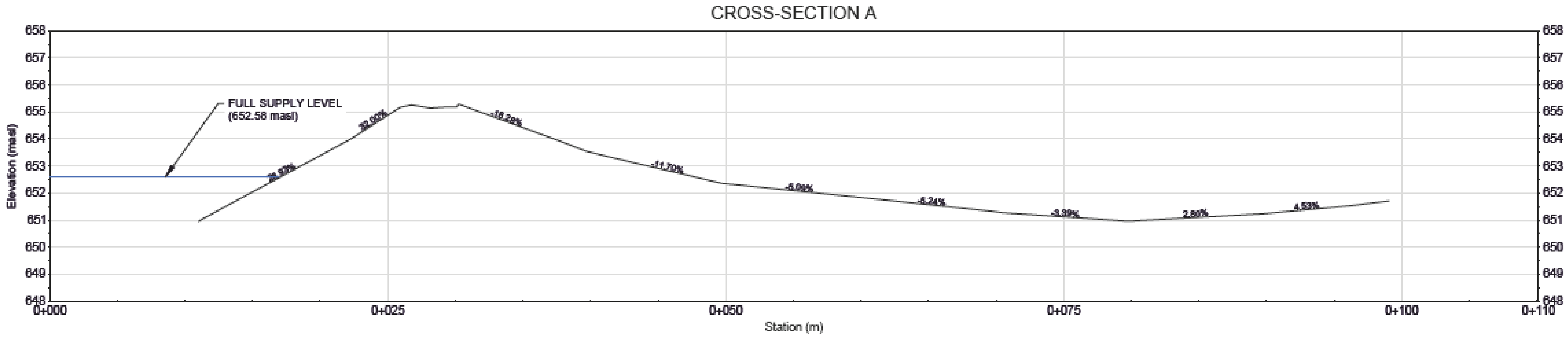
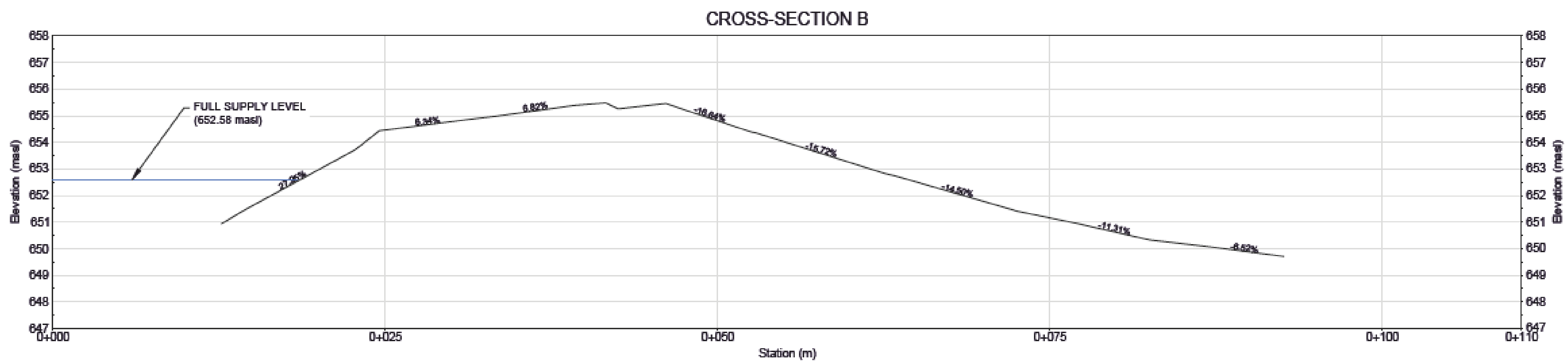
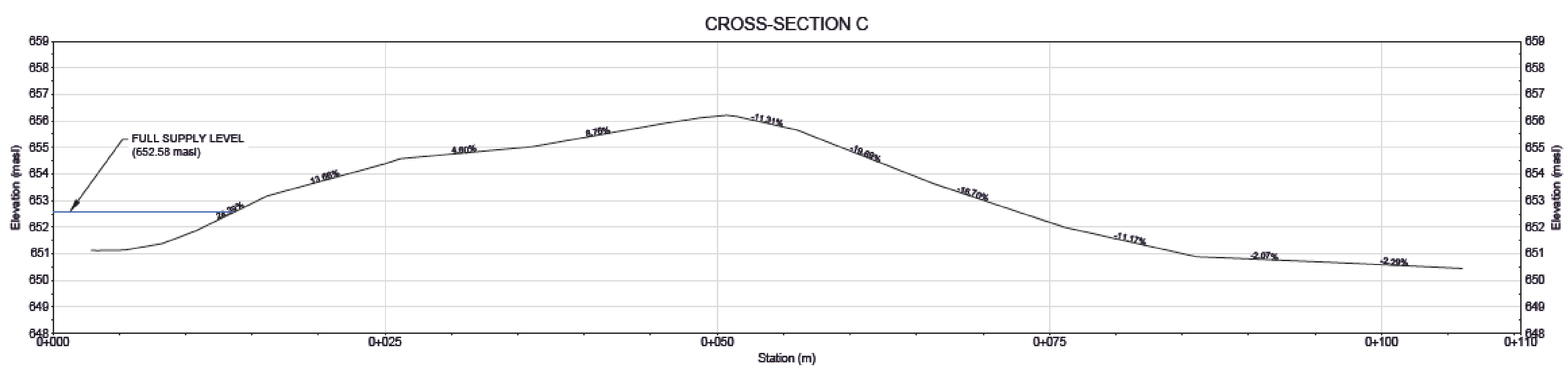






LEGEND

NOTES

1. Drawings coordinates are in UTM, NAD 83 Zone 11.
2. Distances are in metres (m).
3. Elevations are in metres above sea level (masl).

NOT FOR CONSTRUCTION

DISCLAIMER

REFERENCE DRAWINGS

DWG No	DESCRIPTION

REVISIONS

REV	DATE	DESCRIPTION	DES	DRN	CHK	APP
PA	2021-01-07	ISSUED FOR INFORMATION	CD	AC	CD	AJ

H 1:400 — 0, 5, 10, 15, 20 m

V 1:200 — 0, 2.5, 5, 7.5, 10 m

SNC·LAVALIN

CLIENT	PROJECT LOCATION
CITY OF GRANDE PRAIRIE	BEAR RIVER CONTROL STRUCTURE GRANDE PRAIRIE, ALBERTA

TITLE

CROSS-SECTIONS

DATE	2020-10-19	DWG No	676065-0000-4EDD-1003	FIG	4	REV	PA

Inundation Mapping

1 Key Map

2 Upstream Bear River Inundation Mapping – 1:1000 Year Flood – Map 1

3 Upstream Bear River Inundation Mapping – 1:1000 Year Flood – Map 2

4 Upstream Bear River Inundation Mapping – 1:1000 Year Flood – Map 3

5 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 4

6 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 5

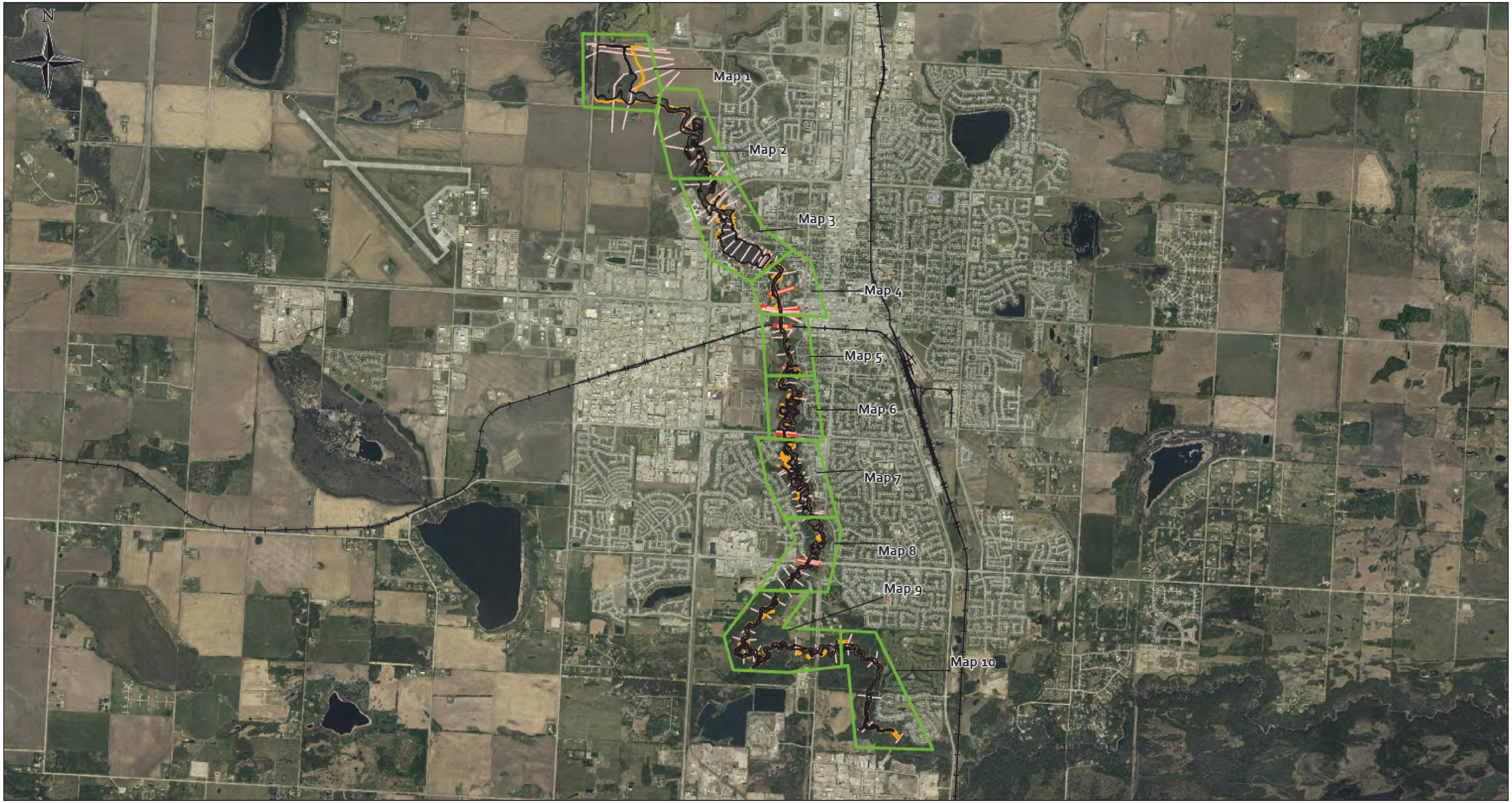
7 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 6

8 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 7

9 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 8

10 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 9

11 Bear River Dam Failure Inundation Mapping – 1:1000 Year Flood – Map 10



LEGEND

- Map Extent
- Pedestrian Bridges
- Cross Sections
- Bridges
- Roads
- Railway
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

0 350 700 1,400 2,100 2,800 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

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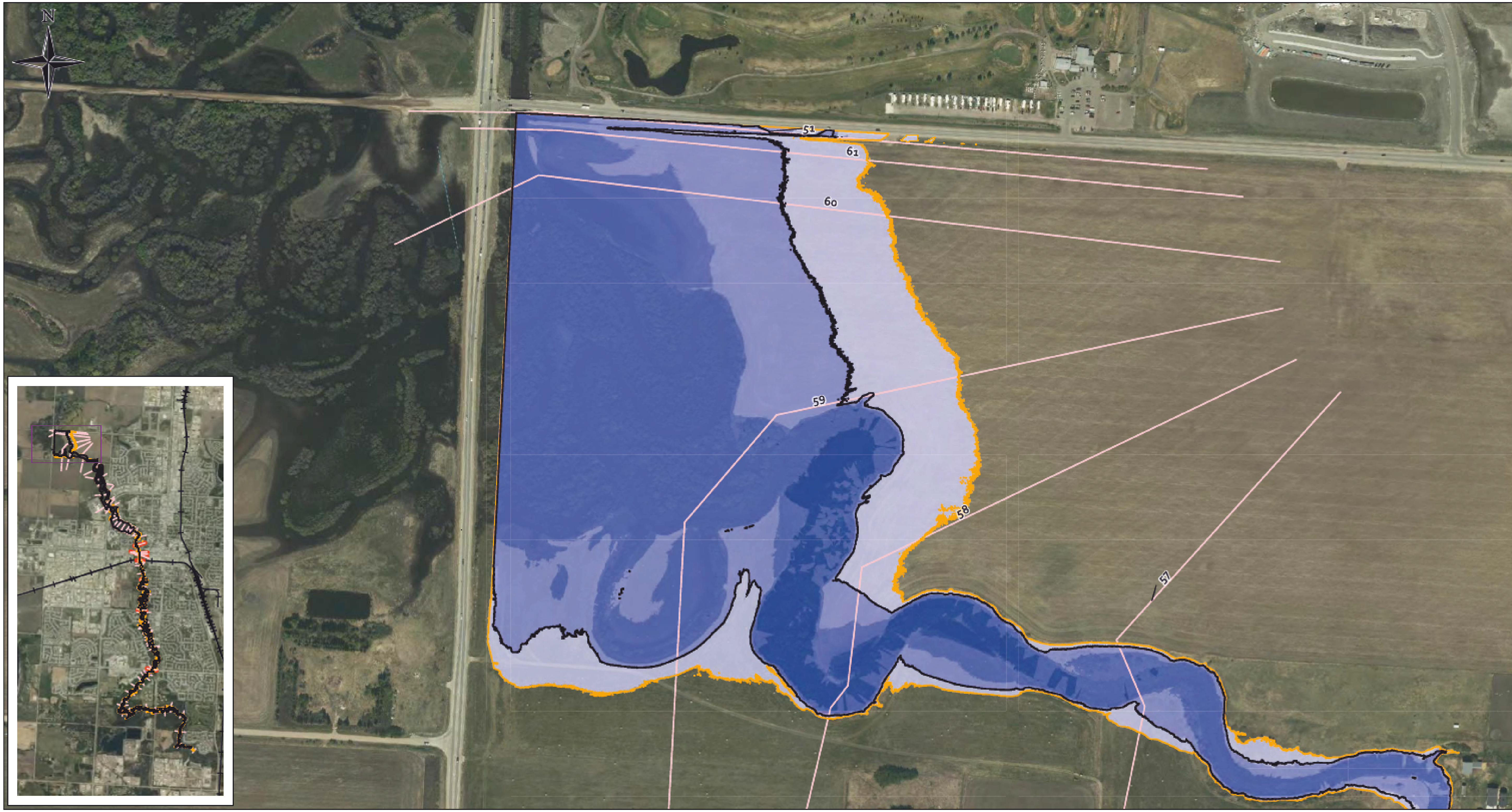
CLIENT NAME: City of Grande Prairie	PROJECT LOCATION: City of Grande Prairie

Key Map

BY: ECH	SCALE: 1:50,000	DATE: 2021-03-01	REF No: REV:
CHK'D: CH/BR	PROJ COORD SYS: NAD 1983 CSRS 10TM AEP Resource		676065-001



LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 -1 m
- 1 -2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 35 70 140 210 280 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

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3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

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CLIENT NAME: City of Grande Prairie	PROJECT LOCATION: City of Grande Prairie		
Upstream Bear River Inundation Mapping - 1:1,000-year Flood - Map 1			
BY: ECH	SCALE: 1:5,000	DATE: 2021-03-01	REF No: 676065-002-1 REV:
CHK'D: CH/BR	PROJ COORD SYS:		

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 40 80 160 240 320 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

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CLIENT NAME: City of Grande Prairie	PROJECT LOCATION: City of Grande Prairie

Upstream Bear River Inundation Mapping - 1:1,000-year Flood - Map 2

BY: ECH	SCALE: 1:5,700	DATE: 2021-03-01	REF No: REV:
CHK'D: CH/BR	PROJ COORD SYS:		676065-002-2

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LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 45 90 180 270 360 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

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CLIENT NAME: City of Grande Prairie	PROJECT LOCATION: City of Grande Prairie

Upstream Bear River Inundation Mapping - 1:1,000-year Flood - Map 3

BY: ECH	SCALE: 1:6,500	DATE: 2021-03-01	REF No: REV:
CHK'D: CH/BR	PROJ COORD SYS:		676065-002-3

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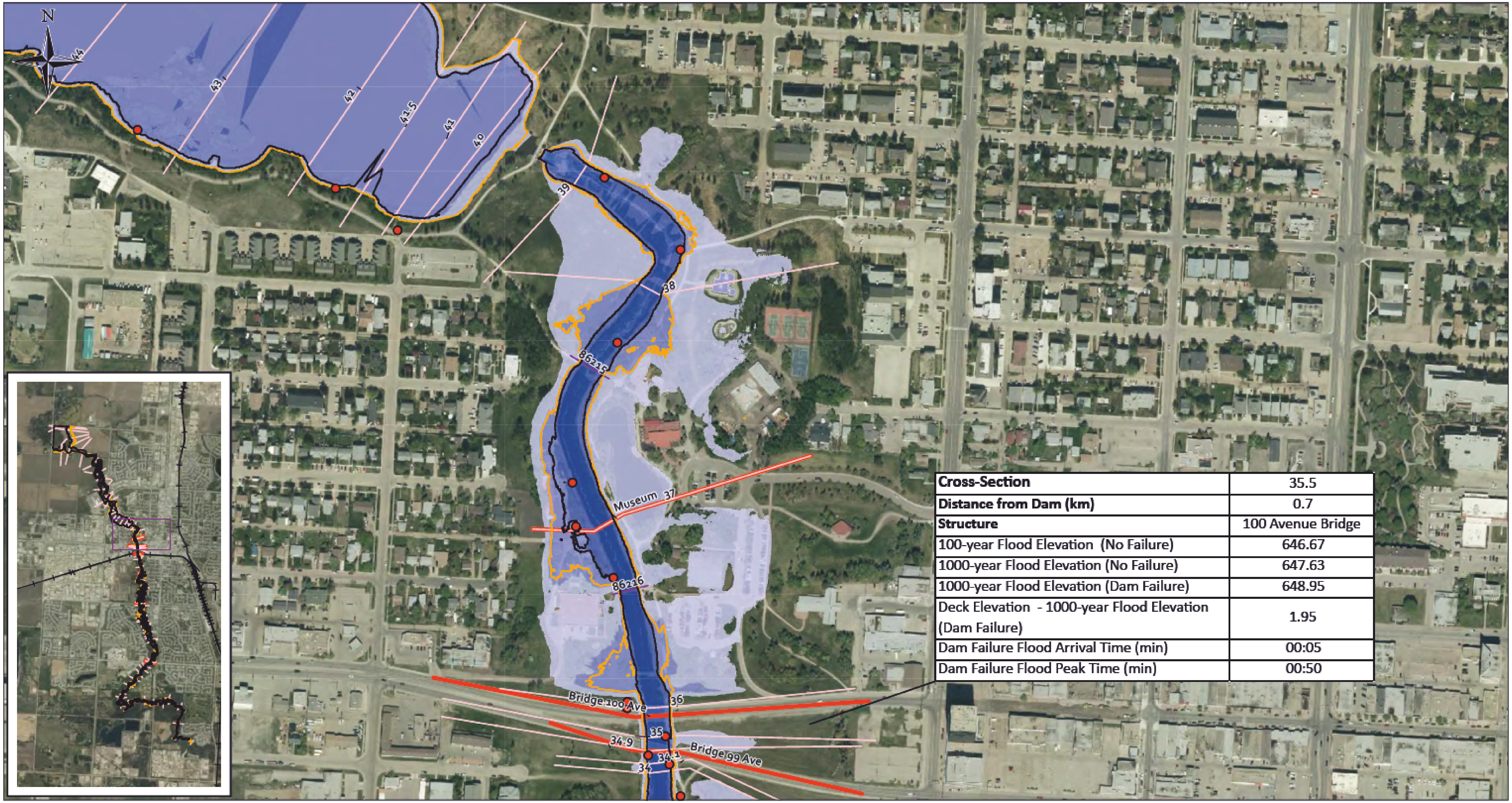

Cross-Section	35.5
Distance from Dam (km)	0.7
Structure	100 Avenue Bridge
100-year Flood Elevation (No Failure)	646.67
1000-year Flood Elevation (No Failure)	647.63
1000-year Flood Elevation (Dam Failure)	648.95
Deck Elevation - 1000-year Flood Elevation (Dam Failure)	1.95
Dam Failure Flood Arrival Time (min)	00:05
Dam Failure Flood Peak Time (min)	00:50

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 25 50 100 150 200 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

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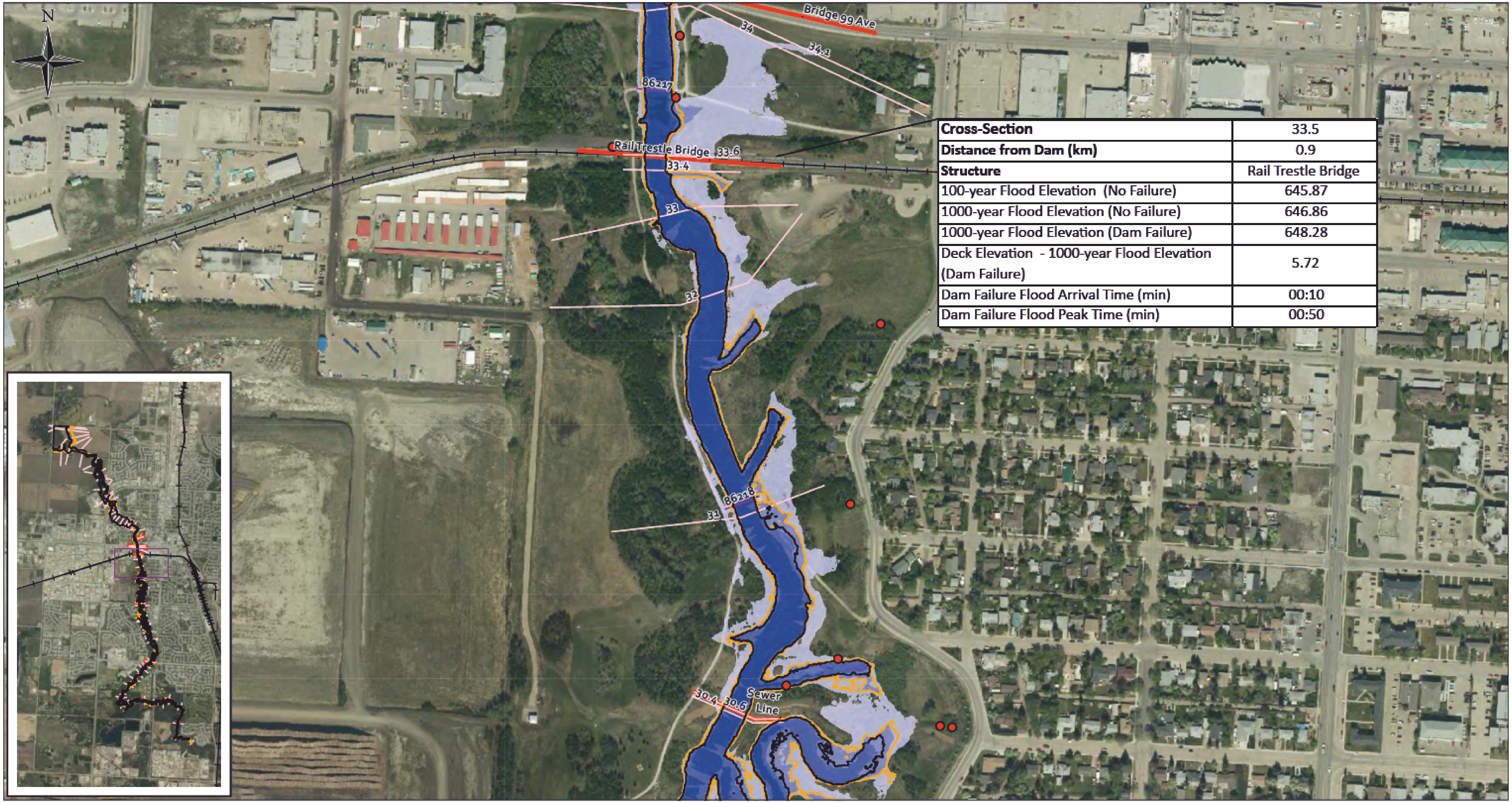
CLIENT NAME: City of Grande Prairie

PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood- Map 4

BY: ECH	SCALE: 1:4,200	DATE: 2021-03-01	REF No: REV:
CHK'D: CH/BR	PROJ COORD SYS:		676065-002-4

MXD Path: \\sli\2606\projects\LOB\EIAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx



Cross-Section	33.5
Distance from Dam (km)	0.9
Structure	Rail Trestle Bridge
100-year Flood Elevation (No Failure)	645.87
1000-year Flood Elevation (No Failure)	646.86
1000-year Flood Elevation (Dam Failure)	648.28
Deck Elevation - 1000-year Flood Elevation (Dam Failure)	5.72
Dam Failure Flood Arrival Time (min)	00:10
Dam Failure Flood Peak Time (min)	00:50

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 25 50 100 150 200 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

SNC·LAVALIN

CLIENT NAME: City of Grande Prairie

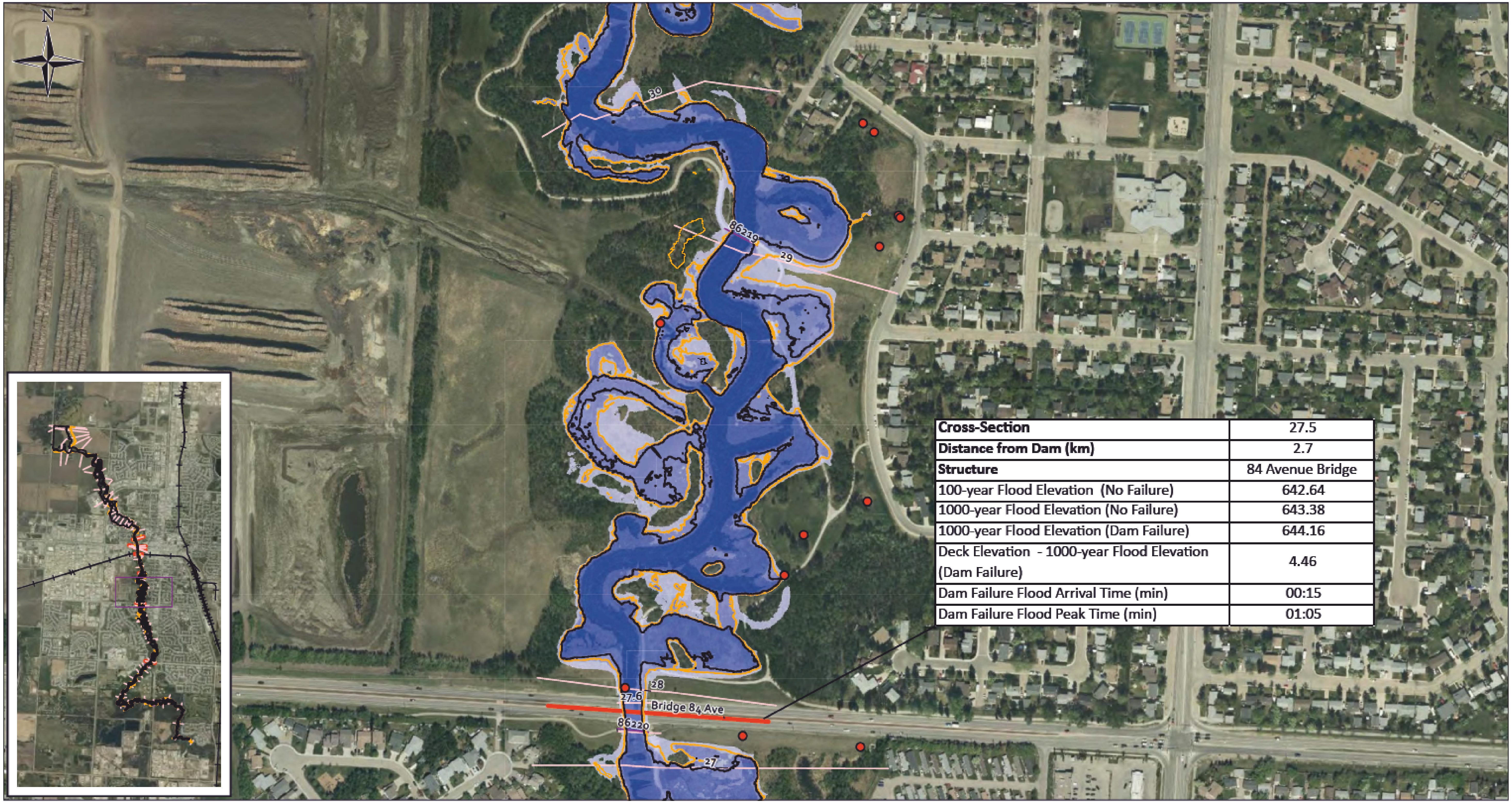
PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood – Map 5

BY: ECH | SCALE: 1: | DATE: 2021-03-02 | REF No: 676065-002-5 | REV:

CHK'D: CH/BR | PROJ COORD SYS:

MXD Path: \\ali2806\projects\LOB\EIAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx



Cross-Section	27.5
Distance from Dam (km)	2.7
Structure	84 Avenue Bridge
100-year Flood Elevation (No Failure)	642.64
1000-year Flood Elevation (No Failure)	643.38
1000-year Flood Elevation (Dam Failure)	644.16
Deck Elevation - 1000-year Flood Elevation (Dam Failure)	4.46
Dam Failure Flood Arrival Time (min)	00:15
Dam Failure Flood Peak Time (min)	01:05

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 25 50 100 150 200 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
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SNC·LAVALIN

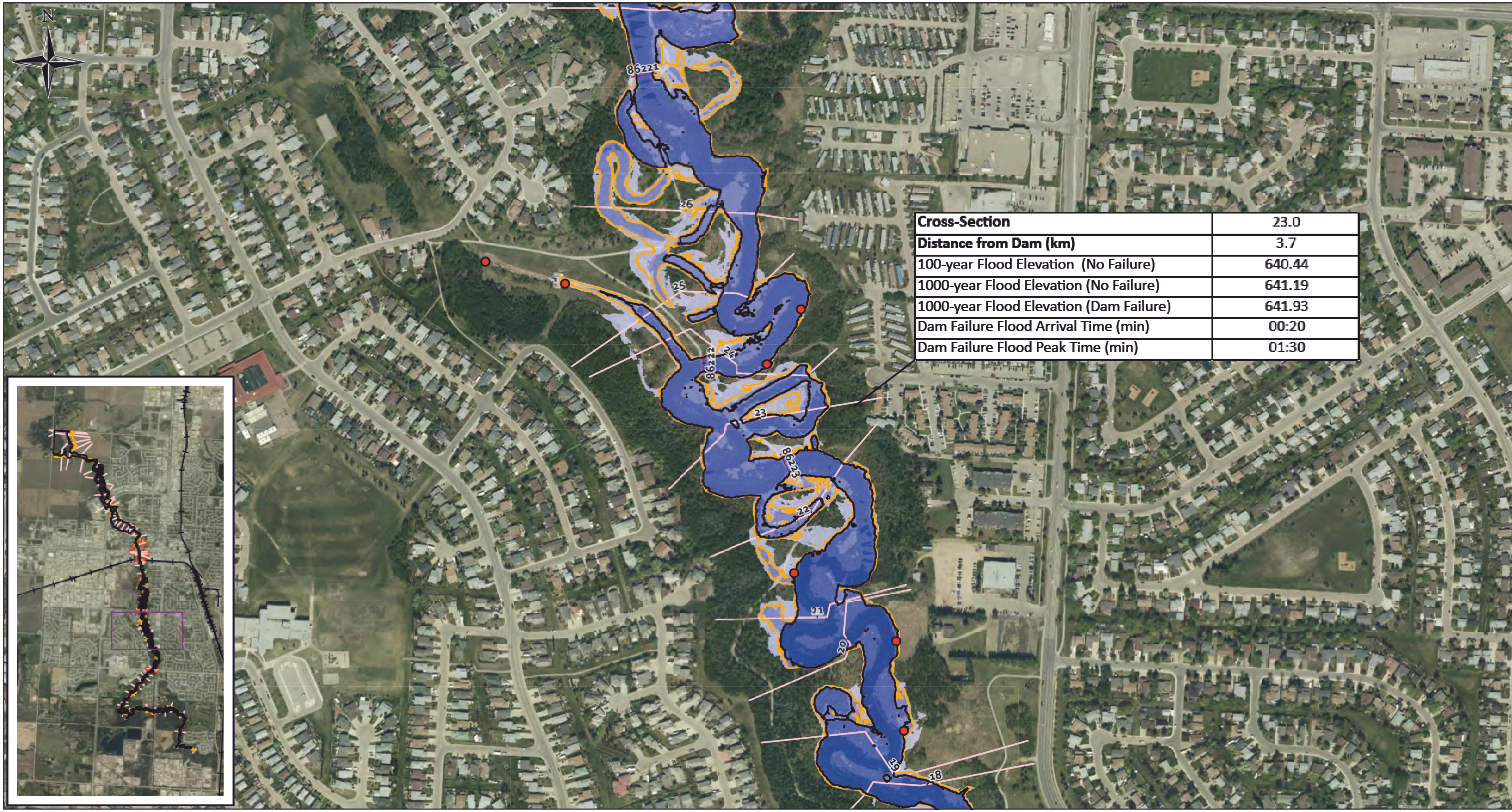
CLIENT NAME: City of Grande Prairie

PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood- Map 6

BY: ECH	SCALE: 1:4,100	DATE: 2021-03-01	REF No: 676065-002-6	REV:
CHK'D: CH/BR	PROJ COORD SYS:			

MXD Path: \\sli2806\projects\LOB\EIAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx



Cross-Section	23.0
Distance from Dam (km)	3.7
100-year Flood Elevation (No Failure)	640.44
1000-year Flood Elevation (No Failure)	641.19
1000-year Flood Elevation (Dam Failure)	641.93
Dam Failure Flood Arrival Time (min)	00:20
Dam Failure Flood Peak Time (min)	01:30

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 35 70 140 210 280 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

SNC·LAVALIN

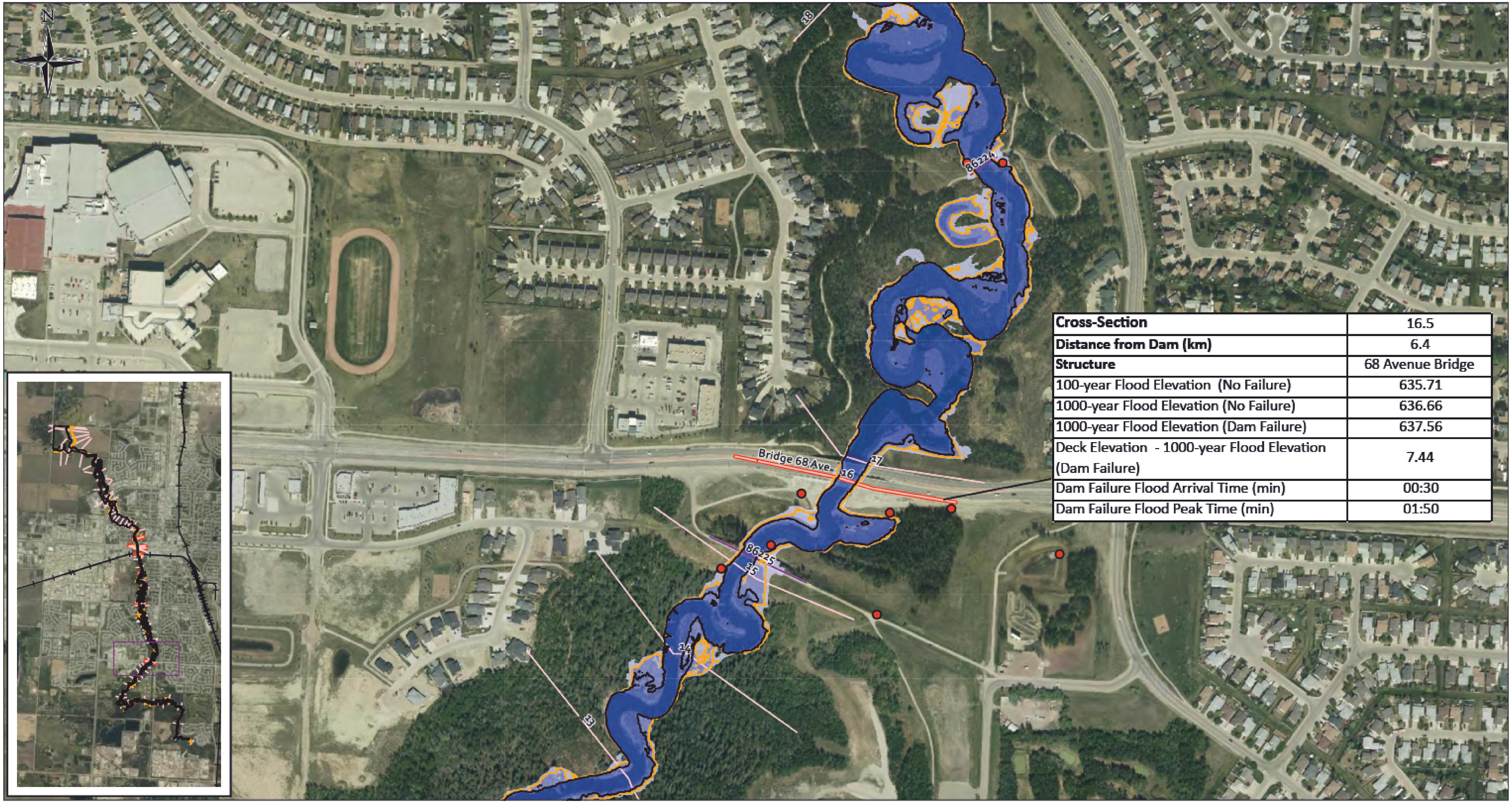
CLIENT NAME: City of Grande Prairie

PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood- Map 7

BY: ECH	SCALE: 1:5,000	DATE: 2021-03-01	REF No: REV:
CHK'D: CH/BR	PROJ COORD SYS:		676065-002-7

MXD Path: \\ali2606\projects\LOB\EIAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx



Cross-Section	16.5
Distance from Dam (km)	6.4
Structure	68 Avenue Bridge
100-year Flood Elevation (No Failure)	635.71
1000-year Flood Elevation (No Failure)	636.66
1000-year Flood Elevation (Dam Failure)	637.56
Deck Elevation - 1000-year Flood Elevation (Dam Failure)	7.44
Dam Failure Flood Arrival Time (min)	00:30
Dam Failure Flood Peak Time (min)	01:50

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 30 60 120 180 240 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

SNC·LAVALIN

CLIENT NAME: City of Grande Prairie

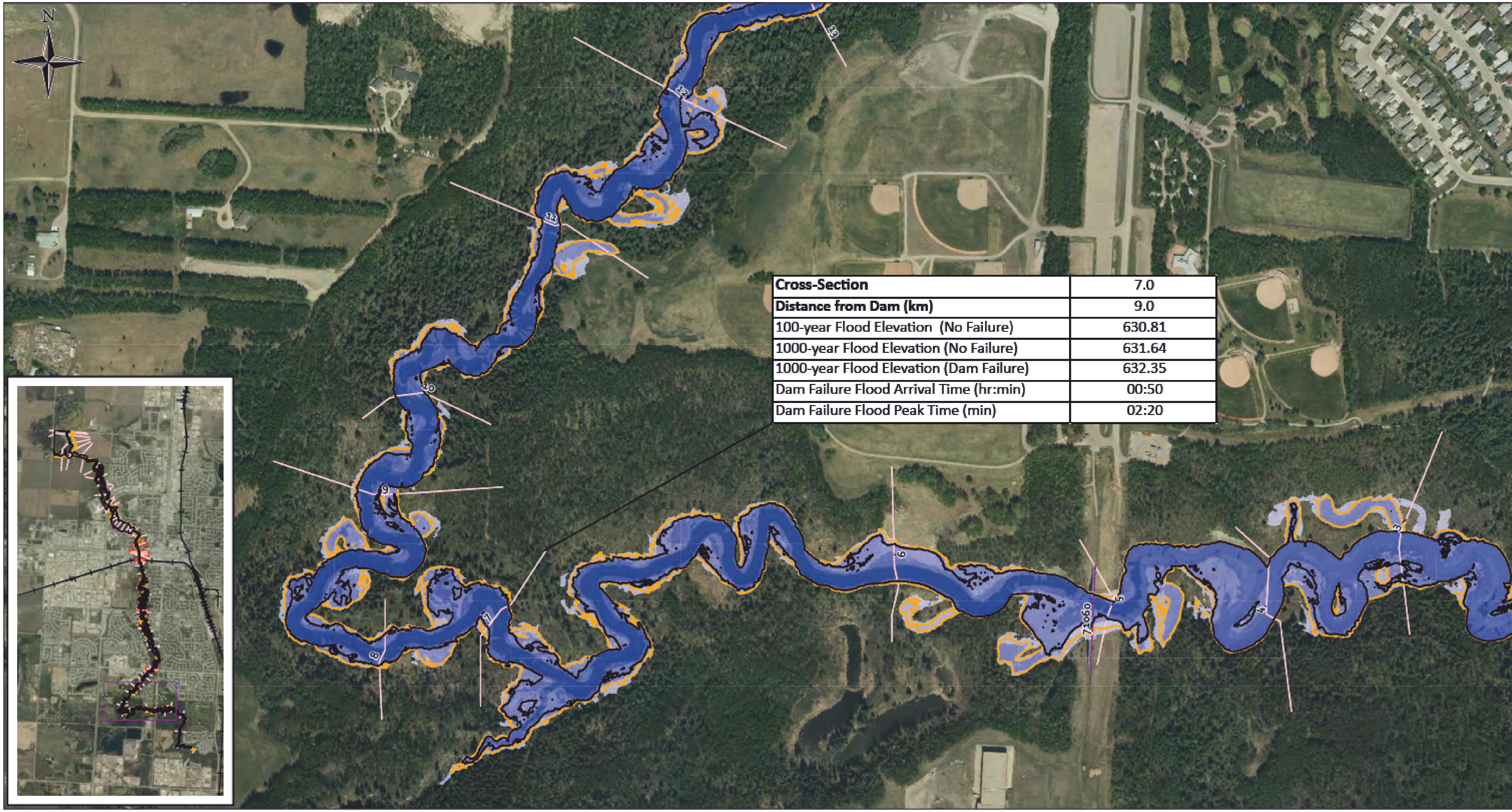
PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood – Map 8

BY: ECH | SCALE: 1: | DATE: 2021-03-02 | REF No: 676065-002-8 | REV:

CHK'D: CH/BR | PROJ COORD SYS:

MXD Path: \\ail2606\projects\LOB\EIAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx



Cross-Section	7.0
Distance from Dam (km)	9.0
100-year Flood Elevation (No Failure)	630.81
1000-year Flood Elevation (No Failure)	631.64
1000-year Flood Elevation (Dam Failure)	632.35
Dam Failure Flood Arrival Time (hr:min)	00:50
Dam Failure Flood Peak Time (min)	02:20

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 35 70 140 210 280 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

SNC·LAVALIN

CLIENT NAME: City of Grande Prairie

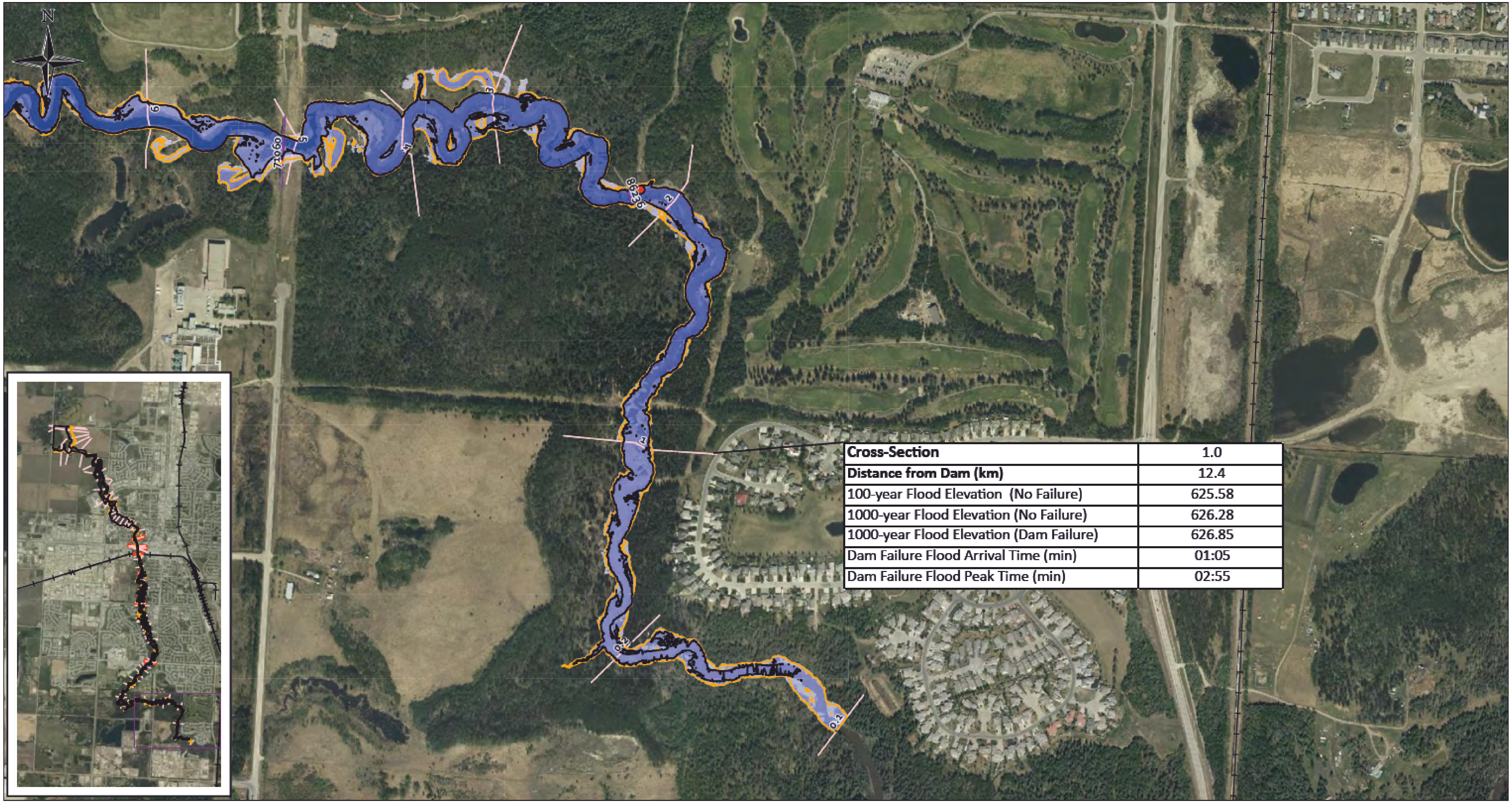
PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood- Map 9

BY: ECH | SCALE: 1:5,150 | DATE: 2021-03-01 | REF No: 676065-002-9 | REV:

CHK'D: CH/BR | PROJ COORD SYS:

MXD Path: \\ali2606\projects\LOB\EIAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx



Cross-Section	1.0
Distance from Dam (km)	12.4
100-year Flood Elevation (No Failure)	625.58
1000-year Flood Elevation (No Failure)	626.28
1000-year Flood Elevation (Dam Failure)	626.85
Dam Failure Flood Arrival Time (min)	01:05
Dam Failure Flood Peak Time (min)	02:55

LEGEND

- Stormwater Outlets
- Pedestrian Bridges
- Bridges
- Cross Sections
- Railway
- Roads
- 1:100-year Flood Inundation Extent (No Dam Failure)
- 1:1,000-year Flood Inundation Extent (No Dam Failure)

1:1,000-year Flood Inundation Depth (Dam Failure)

- 0 - 1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5.2 m

0 50 100 200 300 400 Meters

REFERENCES

1. SNC-Lavalin, City of Grande Prairie, ESRI Base Imagery.

NOTES

1. Original in colour.
2. Numerical scale reflects full-size print. Print scaling will distort this scale, however scale bar will remain accurate.
3. Intended for illustration purposes, accuracy has not been verified for construction or navigation purposes.

SNC·LAVALIN

CLIENT NAME: City of Grande Prairie

PROJECT LOCATION: City of Grande Prairie

Bear River Dam Failure Inundation Mapping – 1:1,000-year Flood- Map 10

BY: ECH	SCALE: 1:7,450	DATE: 2021-03-01	REF No: REV:
CHK'D: CH/BR	PROJ COORD SYS:		676065-002-10

MXD Path: \\tall2606\projects\LOBE\IAM-BC\GIS_Directory\Temporary_Projects\676065 Bear River Control Structure\4.5.1 GIS\676065_Pro\676065_Pro.aprx

Appendix I

Site Inspection Report

SNC·LAVALIN

DAM SAFETY INSPECTION FORM

Facility Name: Bear River Control Structure
Location: City of Grande Prairie
Description: Dam Safety Review (DSR)
Purpose: Site Inspection for Dam Safety Review

Date of 1st Inspection: October 15, 2020
Weather: 5°C, partly cloudy, ~1 cm of snow from previous night

Persons Present During 1st Inspection:

NO.	NAME	ORGANIZATION
1	Alistair James	SNC-Lavalin
2	Chris Duncan	SNC-Lavalin
3	Haimanot Yadete	SNC-Lavalin
4	Laura Jones	SNC-Lavalin
5	Richard Sali	City of Grande Prairie
6	Mike Harvard	City of Grande Prairie

Date of 2nd Inspection: June 8, 2021
Weather: 17°C, sunny

Persons Present During 2nd Inspection:

NO.	NAME	ORGANIZATION
1	Alistair James	SNC-Lavalin
2	Chris Duncan	SNC-Lavalin
3	Richard Sali	City of Grande Prairie
4	Mike Harvard	City of Grande Prairie

List of Areas for Inspection:

1. Main Dam
2. Reservoir Shorelines and Downstream Channels
3. Concrete Structures
4. Mechanical and Electrical Structures

SNC·LAVALIN

City of Grande Prairie Bear River Control Structure
DAM SAFETY INSPECTION FORM

Summary of Inspection Observations and Identified Deficiencies:

- The dam is in GOOD condition. There were NO significant structural or geotechnical issues that were observed at the time of inspection that can result in any immediate dam safety concerns.
- A summary of inspection observations and recommended actions is given in the following table.

Recommended Actions:

Item	Summary of Inspection Observations	Recommended Actions
20-01	There are a number of trees and bushes growing on the upstream slopes, crest, and downstream slopes of the dam.	The trees (particularly the large and all deciduous trees) and bushes on the dam should be removed at some point in the next few years.
20-02	There is a bush growing within the fenced access at the top of the spillway that prevents immediate access to the northern gate and its mechanism.	We recommend that the vegetation be removed or trimmed to prevent obstruction.
20-03	Depressions were observed on the north side of the downstream slope of the dam. This may be the location of the original spillway	Monitor this area for any changes, water seepage, or further movement.
20-04	Erosion channels are developing above the riprap along the spillway downstream wing walls.	The erosion should be repaired, and the riprap armouring should be extended higher up the channel bank along the spillway wing walls to prevent further erosion.
20-05	The spillway approach boom was not in place.	The boom should be reinstated and a planned maintenance occur to remove debris from the boom following storm events.
20-06	The reservoir is filled with sediment.	The capacity of the dead storage of the reservoir is almost lost to sediment transported from upstream. Monitoring of sediment deposit will be required to assess the impact on the loss of live storage of the reservoir. Dredging of sediment might be required accordingly.
20-07	Two large cracks were observed in the concrete spillway that expose rebar.	Cracks that expose rebar should be repaired to minimize corrosion risk and maintain dam integrity and prolong the structure's life.
20-08	There are bushes and tree branches accumulated on top of the gates and horizontal girders. Tree branch was caught on the south arm of the south gate as well. Minor damages have been shown on the J seal from the debris accumulating on top of the gates.	The affected areas on the gates should be cleared from branches and debris.
20-09	Debris was seen wedged or hanged between the cables and skin plate.	The condition of the connection points between the cables and skin plates at the bottom of the gates shall be checked regularly for damage or corrosion and any debris or branches shall be removed.

Item	Summary of Inspection Observations	Recommended Actions
20-10	Corrosion is forming on the gate hoisting equipment. Cable drums and pulleys were showing light corrosions at the contact points with the cables. The block bearings, couplings and drive shafts show minor corrosions.	Recommended that the equipment be painted to prevent corrosion.
20-11	The hoist hand wheels do not have any lock-out devices.	Recommend removal or lock-out of the hoist hand wheels to prevent unauthorised operation of the gates.
20-12	There is no preventative maintenance program for the gates and hoisting equipment. Since 2009 there has been no maintenance performed on the equipment.	A maintenance program should be developed.
20-13	The sensor on the south gate actuator indicating overheating is faulty.	The sensor should be corrected.
20-14	The bottom seal on the north gate is damaged in the center resulting in leakage under the gate when fully closed.	The seal should be replaced.
20-15	Electrical cabinet grounding cable is disconnected from grounding rod and bond connection to fence is not sufficient to provide adequate grounding.	Re-instate grounding connection.
20-16	There are only two danger signs located on either side of the spillway along the access path for public warning and notification.	Recommended to install warning signs at public access points to the reservoir, upstream of the dam, and along the pathway access points to the northeast/southwest of the dam.

Earth Structures

1. Main Dam

Crest

Condition	Remarks/Description
Surface Cracking/Scarps	None observed in dam. Minor cracking in asphalt path (**Photo 1**).
Horizontal Alignment	No observed movement (**Photo 2**).
Settlement	None observed.
Depression/Sinkhole	None observed.
Surface Protection	Well vegetated with established park grasses that are routinely mowed.
Vegetation	Well vegetated with established park grasses that are routinely mowed. There are also several trees of varying size on the crest (**Photo 3**).
Animal Burrows	One observed at the joint between the dam crest and spillway concrete on the south side of the spillway (**Photo 4**).
Other	There is a buried sanitary sewer line that crosses the dam crest (**Photo 5**). The line is buried along most of the crest and is exposed where it crosses the spillway. There are also associated manholes and cathodic protection on either side of the spillway.

Upstream Slope

Condition	Remarks/Description
Slope Stability	Indications of instability were not observed during the inspection (**Photo 6**).
Slope Protection	Riprap extending up the slope, with vegetation within the upper riprap and on the upper slopes.
Upstream Riprap	The upstream riprap consists of well graded rounded cobbles and boulders between 100 mm and 300 mm in size (**Photo 7**). The riprap is in fair condition, though it is overgrown with vegetation in parts.
Erosion	None observed.
Depression/Sinkhole	None observed.
Vegetation	Well vegetated with a mixture of trees, native grasses, bushes, and shrubs (**Photo 8**).
Animal Burrows	None observed.
Other	n/a

Downstream Slope

Condition	Remarks/Description
Slope Stability	Indications of instability were not observed during the inspection (**Photo 9**, **Photo 10**, **Photo 11**, and **Photo 12**).
Slope Protection	Well vegetated with established park grasses that are routinely mowed.
Erosion	None observed.
Depression/Sinkhole	Small depressions we observed on the north side of the downstream slope (**Photo 13**). These may be the location of the original spillway.
Vegetation	Well vegetated with established park grasses that are routinely mowed. There are also several trees of varying size on the downstream slope.
Animal Burrows	None observed.
Drainage System / Seepage	No drainage system. No seepage observed.
Other	n/a

Instrumentation

Condition	Remarks/Description
Observation Well	n/a
Piezometer	n/a
Slope Indicator	n/a
Weir	n/a
Deformation Monitoring	n/a
Others	n/a

Downstream Toe Area

Condition	Remarks/Description
Surface Condition	Good, indications of instability were not observed during the inspection (**Photo 14** and **Photo 15**).
Movement	None observed.
Depression/Sinkhole	None observed.
Drainage System / Seepage	No drainage system or toe ditch. No seepage observed.
Vegetation	Well vegetated with established park grasses that are routinely mowed.
Animal Burrows	None observed.
Other	n/a

2. Reservoir Shorelines and Downstream Channels

Upstream Reservoir

Condition	Remarks/Description
Slope Condition	Good, indications of instability were not observed during the inspection (**Photo 16** and **Photo 17**).
Surface Protection	Riprap covering the upstream dam slope, as discussed previously. Upstream from the dam, the reservoir shorelines are vegetated.
Erosion	No significant erosion observed.
Movement	None observed.
Vegetation	Well vegetated with a mixture of trees, native grasses, bushes, and shrubs.
Reservoir Sedimentation	The reservoir is filled with sediment and during the site visit the low flow condition forms a meandering river and shallow pool. (**Photo 18**)
Others	The spillway approach boom was not in place.

Downstream Channel - Service Spillway

Condition	Remarks/Description
Sidewall/Slope Condition	The slopes of the downstream channel are generally in good condition, with no major indications of instability and minor erosion (**Photo 19** and **Photo 20**).
Surface Protection	Armoured with gabions immediately downstream of the spillway chute (**Photo 21**). Vegetated beyond the gabions.
Erosion	Erosion channels are developing above the riprap along the spillway downstream wing walls (**Photo 22**). Minor sloughing observed on north bank of downstream channel (**Photo 23**).
Movement	None observed.
Vegetation	Well vegetated with a mixture of trees, native grasses, bushes, and shrubs.
Others	There is a sizeable amount of displaced rock just beyond the bottom of the stilling basin (**Photo 24**). It is unclear where this riprap came from, as the gabions all appear to be in place and intact. It was confirmed during the 2021 inspection that the channel riprap is intact adjacent to the stilling basin, with no visible undermining of the end of the basin.

Other Aspects

Condition	Remarks/Description
Access Road	An asphalt path provides public access to the dam with a bridge crossing the spillway. The path is in good condition.
Signs and Public Safety	“DANGER NO TRESPASSING” signs on the chain link fence on both sides of the spillway. No other signage.
Fence	A chain link fence with locked gates prevents public access to the spillway and gate controls.

Condition	Remarks/Description
Others	There is a bush growing within the fenced access at the top of the spillway that prevents immediate access to the northern gate and its mechanism.

Concrete Structures

1. Service Spillway

Headworks

Condition	Remarks/Description
Type	Two bay cast in place concrete retaining structure, controlled by two radial gates (**Photo 25** and **Photo 26**).
Concrete Condition	The headworks are in satisfactory condition
Condition of Joints	The concrete joints were observed to be in good condition
Movement	None observed.
Access	Headworks are accessed via an asphalt path.
Other	

Chute Slab

Condition	Remarks/Description
Concrete Condition	Concrete is in satisfactory condition with moderate roughness and no major cracking (**Photo 27** and **Photo 28**).
Condition of Joints	Slab joints are in satisfactory condition.
Movement	None observed.
Drainage/Underdrainage	n/a
Access	No ladder or stairway access
Other	

Chute Walls

Condition	Remarks/Description
Concrete Condition	In most locations, concrete is in satisfactory condition with no major deterioration (**Photo 29**, **Photo 30**, **Photo 31**, and **Photo 32**). There are two major cracks in the walls at joint locations.
Condition of Joints	There is a significant crack in the second joint down the spillway on both the south and north sides that should be repaired. (**Photo 33** and **Photo 34**)
Movement	None observed.
Other	

Stilling Basin

Condition	Remarks/Description
Concrete Condition	Concrete is in satisfactory condition with moderate roughness and no major cracking. A few of the energy dissipation baffles have corners/edges chipping away, but no exposed rebar (**Photo 35**).
Condition of Joints	Slab joints are in satisfactory condition.
Movement	None observed.
Drainage/Underdrainage	n/a
Access	No ladder or stairway access
Other	Some sediment build-up (~100 mm) in the central middle third of the basin, between the upstream and central rows of baffles.

Mechanical & Electrical Structures

1. Spillway Gate & Hoists

Gates

Condition	Observation: Sketch, Measure, Photograph, Locate (SMPL)
Gate Structure – Pivot Bracket and Gates c/w Gate Arms	Pivot Bracket Connection: › South Gate & North Gate; The bracket connection plates, concrete connection bolts and pivot bracket grout at connection points were in good condition with no signs of damage Pivot Pins: › South Gate & North Gate; pivot pins were in good condition with minor surface corrosion. Pivot Point: › South Gate & North Gate; a clear movement gap was noted between the pivot bracket and gate arm at connection points; the alignment was true at both connection points. No point of contact between the brackets and gate arms was evident during the gate test; no paint damage or corrosion to suggest contact was noted. Refer to **Photo 36**. Gate Arms: › South Gate; South Arm; Tree branch was caught on the gate arm, located away from the arm pivot point, the arm was in good condition. › South Gate; North Arm; the gate arm was free of debris and in good condition. › North Gate; South Arm; the gate arm was free of debris and in good condition. › North Gate; North Arm; the gate arm was free of debris and in good condition. Downstream Face of Gate & Top of Gate: › South Gate; debris was collected along the south side of the gate top, around the south cable and within the pockets/horizontal girders on the downstream face of the gate. Refer to **Photo 37**. › North Gate; debris was collected along the gate top and around both cables. Moderate debris collected in the pockets/horizontal girders on the downstream face of the gate. Refer to **Photo 38**. Gate Skin Plates: › South Gate & North Gate; the skin plates were in good condition with no damage noted.

Condition	Observation: Sketch, Measure, Photograph, Locate (SMPL)
Rubber Seals and Seal Path	Sealing: › South Gate; very little flow/leakage when fully closed › North Gate; leakage noted from the middle section of the gate when fully closed. Side J-seals: › South Gate & North Gate; J-seals are in fairly good condition. Minor damage has been shown on the J seal from the debris on **Photo 39**. Little leakage noted. Refer to **Photo 39** and **Photo 40**. However, **Photo 37** shows a gap on the J seal close to the top of the gate for the south gate. Side J-seal retainers; › South Gate & North Gate; J-seal retainers were in good condition with no signs of damage or wear. Side Seal Path/Plate; › South Gate & North Gate; Seal paths/plates where in good condition with a smooth finish. Bottom J-seals: › South Gate; the bottom J-seals could only be viewed from a distance – no damage noted from this view point. › North Gate; the bottom J-seal is highly damaged in the middle section. Refer to **Photo 41**.
Bubbler Systems and Heating	There is no bubbler system or guide heater system fitted to the gates.
Overtopping & Ice Loading	The gates have been over-topped in the past. Now the water level is maintained within 2m-2.6m to avoid overtopping. Cameras and a flow meter and level sensor are used to monitor levels. Ice forms over the entire face of the gate skin plates during the winter. Operations staff noted there is no specific guidance for the water level that should be maintained prior to freezing in the winter, however the level is monitored via the level sensor and kept low (approximately < 2m). Ice sheets collect behind the gate during the winter and build up is exacerbated during freeze thaw cycles. The ice heaves up the wing walls of the structure. Operations staff noted that ice thickness reaches approximately 40cm; this measurement was noted during ice fracture, however specific ice thickness measurements are not currently collected. It was discussed that during the winter of 2020/21 that ice thickness measurements should be collected by The City of Grande Prairie to improve the understanding of the ice loading on the gates.

Gate Hoists

Condition	Observation: Sketch, Measure, Photograph, Locate (SMPL)
Gate Test	Gate test procedure; › South gate; opened via local operation of the actuator to 100%, the operation was noted to be smooth and without noise or vibration. › South gate; closed via local operation of the actuator to full close, the operation was noted to be smooth and with noise or vibration. › North Gate; opened via local operation of the actuator to 88%; the operation was noted to be smooth and without noise or vibration. › North Gate; closed remotely via the control panel to 5%; the operation was noted to be smooth and without noise or vibration. › South Gate; opened remotely via the control panel to 5%; the operation was noted to be smooth and without noise or vibration. › Opening and Closing Speed; The opening and closing speed of each gate was timed versus opening percentage and it was consistent throughout all operations and between the gates. Operations staff noted that there have been no issues to date with alignment of the gates.
Maintenance Frequency/Schedule	There is no maintenance program currently in place for the gates and associated mechanical and electrical equipment. The gates are actuated as required to maintain water level but are not on a set testing schedule. Since installation in 2009 there has been no maintenance performed on the equipment.
Cable Drums and Pulleys	Cable Drums: › South Gate & North Gate; cable drums had minor paint damage and light corrosion at contact points with the cable. Refer to **Photo 42**. Cable Pulleys: › South Gate & North Gate; cable pulleys had minor paint damage and light corrosion at contact points with the cable; no abnormal noises noted during operations of the gates.
Hoist Cables	Cable Condition: › South Gate & North Gate: cables wrap in the design direction and are in good condition with no signs of wear. The cables ran tangent to the skin plate throughout the gate test. Cable Neoprene Belting: › South Gate & North Gate; the strips of neoprene belting at the interface of the cable and the skin plate showed minor signs of compression damage/wear/tear from contact with the cables. Refer to **Photo 40** and **Photo 43**. Cable connection to the skin plates: › Debris was seen wedged or hanged between the cables and skin plate. Refer to **Photo 40**. The condition of the connection points between the cables and skin plates was not observed closely and will be checked thoroughly during the dewatered spillway inspection in 2021.

Condition	Observation: Sketch, Measure, Photograph, Locate (SMPL)
Motor/Limitorque Actuator	South Gate; the actuator was in good condition visually, with no signs of damage. Staff noted that there is an intermittent faulty sensor on the motor control indicating overheating when the unit is powered up. The fault resets after a power cycle, alternatively the fault has often reset once the north gate has been actuated and the user returns to the south gate motor control. During the inspection the fault was not seen (during both local and remote testing of the actuator). No abnormal noises were noted during operation. North Gate; the actuator was in good condition visually, with no signs of damage. No abnormal noises were noted during operation. In the event of a power failure a drill pack and mobile generator is available (stored off the dam site). The manual handwheel is fitted permanently to both actuators; they are not locked out. Refer to **Photo 44**.
Gearbox	South Gate & North Gate; the gearbox was in good condition with no signs of lubrication leaks/seal damage. Minor wear to the paint and light corrosion was noted on the gearbox casing. No abnormal sounds noted during operation.
Hoist Block Bearings, Couplings, and Driveshaft	Block Bearings: › South Gate & North Gate; minor paint damage and corrosion noted to the block bearing bodies, light build up of dirt collected close to the bearing sleeves. Couplings: › South Gate & North Gate; minor paint damage and corrosion noted to the coupling. Driveshaft: › South Gate & North Gate; minor paint damage and corrosion noted to the driveshafts.
General Access to Equipment	The gate hoisting equipment is within a gated, padlocked, chain-link enclosure topped with three rows of barbed wire. The electrical supply cabinet is within the enclosure and the cabinet is locked. Handrails are provided. Operations staff noted that there have been no issues with vandalism in the past.

Electrical

Condition	Observation: Sketch, Measure, Photograph, Locate (SMPL)
Hoists Electrical Supply & Electrical Cabinet	The incoming electrical supply is provided to the electrical cabinet from a nearby transformer. The power supply, control panel and disconnect switch are in good condition. No issues with the components have been noted by operations staff. The flow meter and level sensor power/control box and antenna are located within the cabinet. The flow meter and level sensor power/control box were installed in 2017 and is in good condition. A disconnected grounding cable and grounding rod were noted at the base of the cabinet. Refer to **Photo 45**. A bonding connection was noted from the top of the cabinet to a nearby fence post. Refer to **Photo 46**. Conduit and junction boxes to the actuators were in good condition.
Lighting	Lighting to the dam is provided by two nearby lampposts, one near the south end of the dam and one near the north end. There is no dedicated lighting for the dam (not required). There is no lighting within the electrical cabinet.
Security System	Two security cameras have been installed on the dam in 2020. One camera views the level staff and one camera views the south gate. Investigation is being carried out to adjust the view/positioning of the gate camera to capture both gates. The feed from the camera is live video, which is not stored or recorded. The video feed can be accessed when the user is logged on to the City of Grande Prairie server.
Flow meter and level sensor	A flow meter and level sensor is mounted on the south wing wall. The sensor is currently configured to transmit data to a server every 4 hours. The data transmission interval can be adjusted to an increased frequency during times of water level/flow fluctuation such as spring break-up. Data can be accessed remotely. An alarm is set to inform on-call staff of high-water level via cellphone alert. Data is also pushed to Alberta Rivers.

Attachment I

Photo Location Plan

LEGEND

● # PHOTO LOCATION

NOTES

1. Imagery provided by client (2020).
2. Drawings coordinates are in UTM, NAD 83 Zone 11.
3. Distances are in metres (m).
4. Elevations are in metres above sea level (masl).

NOT FOR CONSTRUCTION

REFERENCE DRAWINGS

DWG No	DESCRIPTION

REVISIONS

REV	DATE	DESCRIPTION	DES	DRN	CHK	APP
PA	2021-01-07	ISSUED FOR INFORAMATION	CD	AC	CD	AJ

1:1,500 — 0, 10, 30, 50 m

1:500 — 0, 5, 10, 15, 20 m

SNC·LAVALIN

CLIENT: CITY OF GRANDE PRAIRIE

PROJECT LOCATION: BEAR RIVER CONTROL STRUCTURE, GRANDE PRAIRIE, ALBERTA

TITLE: DAM SAFETY INSPECTION PHOTO LOCATION PLAN

DATE	2020-11-06	DWG No	676065-0000-4EDD-2001	FIG	I-1	REV	PA

11X17

Date Plotted: June 21, 2021

\\sli1653\Projects QMS\City Of Grande Prairie\676065_ Bear River Control Structure\40_Execution\45_GIS_Dwgs\4.5.2 CAD\676065-0000-4EDD-1000_PA-Drawings.dwg

Attachment II

Site Inspection Photos

Attachment II – Site Inspection Photo Index

Photo 1: South crest area, facing northeast
Photo 2: South crest area, facing southwest
Photo 3: North crest area, facing southwest
Photo 4: Animal burrow on dam crest, adjacent to spillway
Photo 5: Dam crest at spillway location, facing northeast
Photo 6: Upstream slope, south side, facing southwest
Photo 7: Riprap on upstream dam slope
Photo 8: Upstream slope, north side, facing southwest
Photo 8: Downstream slope, south side, facing east
Photo 10: Downstream slope, south side, facing spillway to the north
Photo 11: Downstream slope, north side, facing south
Photo 12: Downstream slope, north side, facing spillway to the west
Photo 13: Depressions on the north side of the downstream slope
Photo 14: South toe area, facing southwest
Photo 15: North toe area, facing southwest
Photo 16: Upstream reservoir south shoreline, facing west
Photo 17: Upstream reservoir north shoreline, facing north
Photo 18: Reservoir filled with sediment
Photo 19: Downstream channel shoreline, facing east
Photo 20: Downstream channel shoreline, facing southeast
Photo 21: Gabions armoring downstream channel
Photo 22: Indication of broken gabion mesh downstream channel embankment
Photo 23: Sloughed area on north side of downstream bank (view impeded by grasses)
Photo 24: Displaced cobbles deposited downstream of the stilling basin
Photo 25: Dam spillway, downstream side
Photo 26: Dam spillway, upstream side
Photo 27: Concrete spillway slab
Photo 28: Concrete spillway slab
Photo 29: Concrete spillway chute, south wall
Photo 30: Concrete spillway chute, south wall
Photo 31: Concrete spillway chute, north wall
Photo 32: Concrete spillway chute, north wall
Photo 33: Concrete spillway chute, joint crack in south wall
Photo 34: Concrete spillway chute, joint crack in north wall
Photo 35: Chipped energy dissipation baffle
Photo 36: South Gate Pivot Point
Photo 37: Debris South Gate
Photo 38: Debris North Gate
Photo 39: J-seal South Gate
Photo 40: J-seal, Seal Retainer and Hoist Cable Belting North Gate
Photo 41: Damaged Base Seal North Gate
Photo 42: Cable Drum North Gate
Photo 43: South Gate Hoist Cable Belting
Photo 44: South Gate Actuator with Handwheel
Photo 45: Disconnected Grounding Wire
Photo 46: Fencing Bonding Cable

Photo 1: South crest area, facing northeast

Photo 2: South crest area, facing southwest

Photo 3: North crest area, facing southwest

Photo 4: Animal burrow on dam crest, adjacent to spillway

Photo 5: Dam crest at spillway location, facing northeast

Photo 6: Upstream slope, south side, facing southwest

Photo 7: Riprap on upstream dam slope

Photo 8: Upstream slope, north side, facing southwest

Photo 9: Downstream slope, south side, facing east

Photo 10: Downstream slope, south side, facing spillway to the north

Photo 11: Downstream slope, north side, facing south

Photo 12: Downstream slope, north side, facing spillway to the west

Photo 13: Depressions on the north side of the downstream slope

Photo 14: South toe area, facing southwest

Photo 15: North toe area, facing southwest

Photo 16: Upstream reservoir south shoreline, facing west

Photo 17: Upstream reservoir north shoreline, facing north

Photo 18: Reservoir filled with sediment

Photo 19: Downstream channel shoreline, facing east

Photo 20: Downstream channel shoreline, facing southeast

Photo 21: Gabions armoring downstream channel

Photo 22: Erosion channel above riprap along downstream wing wall

Photo 23: Sloughed area on north side of downstream bank (view impeded by grasses)

Photo 24: Displaced cobbles deposited downstream of the stilling basin

Photo 25: Dam spillway, downstream side

Photo 26: Dam spillway, upstream side

Photo 27: Concrete spillway chute slab

Photo 28: Concrete spillway chute slab

Photo 29: Concrete spillway chute, south wall

Photo 30: Concrete spillway chute, south wall

Photo 31: Concrete spillway chute, north wall

Photo 32: Concrete spillway chute, north wall

Photo 33: Concrete spillway chute, joint crack in south wall

Photo 34: Concrete spillway chute, joint crack in north wall

Photo 35: Chipped energy dissipation baffle

Photo 36: South Gate Pivot Point

Photo 37: Debris South Gate

Photo 38: Debris North Gate

Photo 39: J-seal South Gate

Photo 40: J-seal, Seal Retainer and Hoist Cable Belting North Gate

Photo 41: Damaged Base Seal North Gate

Photo 42: Cable Drum North Gate

Photo 43: South Gate Hoist Cable Belting

Photo 44: South Gate Actuator with Handwheel

Photo 45: Disconnected Grounding Wire

Photo 46: Fencing Bonding Cable

Photo 47: Birds eye spillway view

Photo 48: Birds eye spillway view (dewatered)

Appendix II

Staff Questionnaire

SNC-Lavalin Inc.
Environment & Geoscience
201, 8915 – 51 Avenue
Edmonton, Alberta, Canada T6E 5J3
780.436.9400

Memorandum

To:	City of Grande Prairie	**Date:**	August 21, 2020
Attention:	Mike Harvard, City of Grande Prairie		
cc:	Richard Sali, City of Grande Prairie		
From:	Chris Duncan, SNC-Lavalin Inc. Alistair James, SNC-Lavalin Inc.	**Project:**	676065
Subject:	Bear River Control Structure Dam Safety Review – Staff Questionnaire (Version 1)		

The City of Grande Prairie (the City) commissioned SNC-Lavalin Inc. (SNC-Lavalin) to conduct an independent Dam Safety Review (DSR) for the Bear River Dam and Control Structure in Grande Prairie, Alberta.

As a part of the DSR process, SNC-Lavalin proposed to prepare a questionnaire and submit it to the City prior to the site inspection. SNC-Lavalin prepared this questionnaire primarily for the appropriate City dam safety staff with the intent to collect important information on City dam safety management practices in place. The questionnaire should be reviewed and answered by all relevant levels of personnel involved in dam safety (Dam Safety Engineer, EOR, Field Operations Staff / Technologists, Senior Manager, etc.) as required.

SNC-Lavalin would appreciate receiving the City's response prior to the site visit and staff interviews, so that any additional relevant information and response to any of our potential follow-up questions can be posed or collected during the site inspection.

These questions are prepared considering the CDA's 2007 Dam Safety Guidelines (2013 revision) and 2016 Dam Safety Review Bulletin and SNC-Lavalin's experience on dam safety and our general understanding of the dam and its appurtenant structures.

Questions are generally organized under different aspects of the dam and its appurtenant structures to meet the intent of the DSR and may have some overlaps. Where response to a question is either partly or completely covered by a previous question, reference can be made to the appropriate question numbers.

The City's responses are to be supplied in an email or letter or memorandum format, presenting our questions with corresponding answers in the same order and numbering.

Dam Safety Management

1. Who is the 'Engineer of Record' for the dam and its related structures? Who has the ultimate responsibility for the safety of this dam and its related structures? As per our APEGA Professional Practice Management Plan the City's CAO (Horacio Galanti, P.Eng)

2. Who is responsible for the day-to-day oversight (monitoring, surveillance, maintenance) of dam safety management at the City for the facilities within the scope of this DSR? Engineering Services staff have been given this responsibility.

3. It is understood that some responsibilities for dam safety (monitoring, regulatory, capital works, etc.) are shared between different divisions within the City. Who (name of person and title) is ultimately accountable to ensure that imminent or potential dam safety issues are addressed in a timely manner? Engineering Services (Richard Sali, Mike Harvard, Kristine Donnelly) and Transportation Services (Robert Carroll, Grant Inman) share the operating responsibility of the spillway

4. How are senior management and/or the key person with ultimate accountability for dam safety kept informed of the status of Bear River dam safety issues? When concerns are noted they are brought forward to CLT

5. What are the criteria for prioritizing which dam safety issues at which dams are addressed? Does the City produce an annual report for senior management or council on Bear River dam safety issues and their status? There hasn't been a yearly report. The last report was done by Golder in relation to a reservoir dredging feasibility study. Safety issues are addressed once observed by staff operating the gates at the spillway. Depending on the severity of the concern and fix implications (

6. Is the decision-making process vetted by different levels of authority within the City? Please describe the process. Once a concern or maintenance item has been brought forward and initially investigated by Engineering Services and a proposed solution is come up with, the proposal goes to CLT (Corporate Leadership Team) for approval and then gets put out for RFP/Tender

7. Who is responsible for the Dam Safety Management System at the City? Is there an organization chart outlining lines of authority as well as roles and responsibilities and accountability (organization charts and RACI charts)? RACI is an abbreviation for Responsible, Accountable, Consulted, Informed. The City doesn't currently have a management system in place

8. Are there performance metrics for dam safety management at the City? How often are the results reviewed or the metrics updated? Not currently in place or they are to maintain compliance of the structure.

9. Does the City utilize the findings and recommendations of a DSR to improve dam safety at its dams? That and to ensure compliance with all regulatory bodies

10. What are the public safety concerns for the Bear River dam? What specific actions have been undertaken at the dam to address public safety? Spillway failure and subsequent downstream infrastructure damage.

11. Is there a staff training program for key individuals responsible for dam safety? How are the technical competencies evaluated? How are staff assessed? Are records of training available? Is there an audit of how training complies with the training policy/plan? There is no formalized training plan or subsequent evaluation, assessment, records of training for the individuals, currently.

12. Is there any ongoing or planned dam safety work for Bear River that the DSR team should be aware off? Not aside from this project

13. What is the main concern of City staff? To have the structure properly classified and brought into compliance, through this DSR, inundation study, and emergency response plan creation

Operations, Maintenance and Surveillance (OMS)

14. Do you have defined operating procedures for normal, unusual, flood and/or emergency conditions at the dam? Who is responsible for reservoir operations at the site (name of person and title)? No defined Operating procedures. Richard Sali, Mike Harvard, Grant Inman

15. The 2003 Radial Gate Review report by Associated Engineering (Section 4.3) recommends using undershot gates based on the city stormwater management plan which considers Bear River reservoir a flood control storage reservoir. Please confirm if the above is still valid.

16. Please confirm the radial gates are not designed to be overtopped. I am unable to confirm

17. During events such as high-level flows in Spring 2018 the gates were partially opened and water was overtopping the gates. Do operational procedures allow for overtopping of the gates during flood events? Don't really have a procedure for operations, except to say that the City would like to maintain a water level that keeps all sediment up stream of the reservoir covered and all water is going under the gates vs over topping.

18. What is the maximum flood event the radial gates have been designed for?

19. What are the procedures for inspecting the dam after a major flood or other situations with potential dam safety implications, such as unusual seepage, large erosion gullies, gates being inoperable, etc.? Has the City established a procedure for incident reporting? We do an informal visual inspection after an event, to look for any oddities

20. What are the triggers for invoking emergency procedures related to unanticipated seepage rates, slumping, flood inflows, etc.? When water levels begin to rise the City raises the gates to allow for more flow

21. Describe the maintenance activities and inspection schedules for site access, dam and public safety measures? There aren't currently any. As needed, we cycle the gates to remove debris downstream

22. Do you have an operations log/record of actions for the subject facility? No

23. Who among the staff are involved in surveillance activities (name of person(s) and title)? Richard Sali (Development and Storm Drainage Manager), Mike Harvard (Development Engineer)

24. What is the schedule to operate flow control equipment (such as pumps)? Is an annual functional test conducted to verify that flow control equipment will operate under normal flows and flood conditions? Do the flow control maintenance procedures include inspection, reporting, repair and follow-up? There aren't any pumps. Flow is controlled by the gates ony

25. Is there a reservoir rule curve? If so, please provide a copy. I believe that this is with the original design drawings previously provided.

Emergency Preparedness (EP)

26. What communications systems are available if there is an emergency? Are there any warning systems in an emergency situation? How are downstream residents, recreationists, local

governments and area visitors warned? They are warned through the implementation of GPREP (Grande Prairie Regional Emergency Partnership) and the protocols put in place for a general emergency response plan through the partnership.

27. Is there a list of all persons and agencies to be notified when a potential or imminent flood emergency is declared? This is done through the Grande Prairie Regional Emergency Partnership (GPREP)

28. Is any training provided on the emergency response procedures? How many people are trained? Is someone trained on the emergency response procedures available at all times? The City doesn't currently have a set response plan. Most managers and Directors are available during emergency's and have the current training to be able to respond.

29. Is information about accessing the site readily available? Does information about accessing the site deal with power outages and extreme weather conditions? No

Geotechnical and Instrumentation

30. SNC-Lavalin understands that the dam does not contain any monitoring instrumentation. Does the City have any plans to install instrumentation? Not currently at this time

31. Who undertakes visual inspections of the dykes/dams and adjacent slopes, in addition to or as part of the OMS surveillance activities? How often are visual inspections conducted? City Staff (Richard Sali, Mike Harvard) visually inspect after extreme events or when going out to adjust the gates.

32. What training has been provided to those conducting the geotechnical inspections? None, above the schooling that was taken to achieve Diploma/Certificates, and continuing education courses.

33. How are the inspections recorded and are they reviewed by an EOR regularly? No

34. What management of vegetation occurs on the slopes of dyke and dam/reservoir slopes? The vegetation is left to naturalize

35. Have there been slumps or erosion on the slopes of the reservoir or the dam since the last DSR? Have there been any significant repairs or maintenance activities on the slopes since the last DSR? There hasn't been significant sloughing or repairs of the reservoir slopes since the Elks Hall slope and outfall repair in 2011. The Last DSR was completed in 2012

36. Are there any paint marks on the wall indicating water level and water design level EL 652.883? Other than Spring 2018, were there any records of water level higher than water design level EL 652.883? Did water level overtop the gate during high water level in May 2020? There are faded paint markings on the south upstream wing wall (all in feet). There are written records of when the gates were adjusted that contain the information.

37. Are there any measurements for ice thickness during winter? (Design ice thickness is 306 mm). No

38. The old trunnion had an anchorage system attached to the foundation while the new trunnion concrete is attached to top of the concrete pier by chemical reinforcement bars. Are there structural calculations for the new trunnion for normal operating water level with/without ice load, flood and

EQ loading? What is the safety factor for each case? They would be within the Bear Creek radial gate replacement project report.

39. Is there any inspection and maintenance record for the stilling basin vent pipe? Is the wiremesh cover still intact to prevent any debris or animals burrowing into the pipe?

Hydrotechnical / Hydrological

40. What have been the most extreme conditions of reservoir level and discharges observed?

41. What is the maximum operating level for the reservoir? 654

42. Do you have in place a program to inspect the spillway and the spillway chute after high floods? Currently we do an informal visual inspection after a high flow event

43. Have you found or detect any erosion at the spillway chute after the passage of a high flood? If the answer is yes, please describe. We have noted the push-up/ movement of rock/gabion, just past the end of the spillway.

44. Has debris blockage ever occurred at the discharge facilities? If yes what when did the blockage occur? And what was the extent of the blockage? Not that has been observed to block the flow and cause excess water elevation upstream

45. Is there a potential for debris from upstream to interfere operations at the site? Yes, there is.

46. Is there a debris management program at the site? When it is observed that there is a build up of debris, the City actuates the gates to wash it downstream.

47. Do ice jams block any flow control equipment or discharge facilities? Is their potential for ice jams having adverse effects on flow control and discharge? There is potential, but this has not been a documented or observed concern.

48. What are the constraints in the operation of the spillway? Is there a requirement to open the two gates in parallel to avoid asymmetrical flow? Was there an asymmetric operation of the spillway gates experienced and was it documented? The only constraints that we limit ourselves to is the amount of opening to limit the flow of water such that we don't cause inundations and damage downstream, due to increased water and flow levels.

49. Were there inundations in the downstream reach caused by the operation of the spillway? At what conditions, period of the year and discharge? There have been inundations downstream, within the Bear Creek Corridor, during the spring freshet

50. It there a critical infrastructure downstream of the spillway (ex. Hwy, hospital, etc.)? There are 3 sets of Arterial Vehicular bridge structures (6 Bridges), 2 Aquatera (Sanitary, Water) Utility bridges, and ?# of pedestrian bridges. There is also the Grande Prairie Museum and Historical Village, and Ernie Radborne Pavilion. (Not sure if these are considered critical)

51. Were there issues with the riprap stability and if affirmative, under what conditions they have occurred?

52. Were there observations of critical conditions with respect to the available freeboard at the dam and when were they experienced (period of the year)? Since my time at the City (2007 to Present), there have been 2 critical conditions in which the water was up to the underside of the concrete walkway (2018 & 2020), both occurred in Spring around the end of April

53. Are there anecdotal records of experienced critical water management conditions that require mentioning?

54. Is there a specific requirement for minimum environmental flow release related to the period of the year? Not that the City is aware of.

Mechanical & Electrical

55. Are there remote indicators for the operation of flow control equipment? No

56. What backup power sources are available in case of emergency? None.

57. Have the backup power sources been tested recently? If yes, were they tested under load? No

58. How are maintenance activities of flow control equipment documented? (log books, records, reports, etc.) no current records

59. How are maintenance activities of flow control equipment planned (maintenance program)? Maintenance has been minimal, with no real maintenance program.

60. How are inspection activities of flow control equipment planned and at what frequency? Would be defaulted to the manufacture's specifications

61. At what frequency flow control equipment is tested and are there any records of the tests? Same as above

62. Are there any spare parts available for gates and hoists (such as actuators, motors, electrical components, seals, wire ropes, couplers)? No

63. Is there any stoplogs available to isolate the radial gates during the inspection? This is required for assessing the condition of the embedded seal and sill plates. If not, what are the options for assessing the condition of the gate embedded parts? The City does have a stop log for one side, not sure about its condition.

64. Have the wire ropes ever replaced for the new hoists? No

65. Has the leakage rate been measured in recent years? No

66. How often the gates are being operated? Dependent on the rate of flow and how much water is coming downstream, Typically weekly.

67. Is there any requirement for the two gates being opened or closed incrementally at the same time (to help the stability of the center pier)? No there is not.

68. When fully opened are the bottom of gates and the trunnions completely clear of water nappe (both during flood and during normal operation)? Not always

Closure

We sincerely appreciate all of your time, effort and information that you will provide regarding management and operations of the facility addressed in this DSR.

Appendix III

Flood Hydrology Review and Update

SNC·LAVALIN

Environment & Geoscience

201, 8915 – 51 Avenue
Edmonton, Alberta, Canada T6E 5J3
780.436.9400

Memorandum

To:	City of Grande Prairie	**Date:**	February 23, 2021
From:	SNC-Lavalin	**Project.:**	676065
Subject:	**Flood Hydrology Review and Update for Bear River Control Structure Dam Safety Review**		

1 Background

The Bear River is a tributary to the Wapiti River which drains into the Smoky River and ultimately to the. Peace River. The 1,566 km^2 watershed area upstream of the Grand Prairie Reservoir includes Bear Lake, agricultural lands, and forested areas. The Bear Lake with a surface area of 33 km^2 plays a significant role in the attenuation of the peak flows to the Grand Prairie reservoir.

The main objective of the hydrological update is to review and update the design flow by incorporating data available since the last DSR report. Since the watershed area at the reservoir inlet is not gauged, a Water Survey Canada (WSC) station on the Grande Prairie Creek is used to derive a relationship between the gauged station and the project site.

The hydrological update commenced by reviewing the Golder Associates 2014 (Golder 2014) Bear River Control Structure Dam Safety Review and the Alberta Environment 2007 (AEP 2007) City of Grande Prairie Flood Risk Mapping Study. As per the review, the Bear River sub-watershed areas are:

- Sub-watershed Bear River at confluence with Grande Prairie Creek: 1,144 km^2
- Sub-watershed Grande Prairie Creek at Bear River confluence: 301 km^2
- Sub-watershed Bear River between confluence with Grand Prairie Creek and Grand Prairie Reservoir: 112 km^2
- Total watershed of Grand Prairie Reservoir: 1,566 km^2

Some of the governing factors that influence the hydrology of the Bear River are:

- The large surface area of the Bear Lake (33 km^2) and the flat gradient of Bear River downstream of the lake to the confluence with Grande Prairie Creek plays a role in significantly attenuating the Bear Lake outflow considering the important size of its watershed (1,144 km^2).

- There is a flow reversal from the Grande Prairie Creek to the section of the Bear River downstream of the Bear Lake. With Bear Lake at high elevation, about 7 to 15 percent of the total flow above the confluence of Grande Prairie Creek will enter Bear Lake (Golder 2014).

2 Data Review and Analysis

WSC hydrometric stations on the Bear River, Grande Prairie Creek, and Bear Lake are used to derive a relationship between the gauging stations and the project site (see **Figure III.1**). WSC 07GE003 is a long-term hydrometric station available on the Grande Prairie Creek with a total catchment area of 140 km^2. WSC 07GE005 is a discontinued hydrometric station on the Bear River with only four years of data (1983 to 1986) and has a total catchment area of 1,510 km^2. In addition, there is a water level gauging station (WSC 07GE004) on the Bear Lake with long-term data from 1967 to 2009. **Table III.1** presents the details of the monitoring stations.

WSC 07GE003 gauging station near Sexsmith is the main station used to drive the flow relationship. The missing maximum daily flow data was filled using a relationship between the instantaneous peak and maximum annual daily flow with power regressing fitting.

Stream flows of the Grande Prairie Creek were monitored during the open-water season (i.e., March to October) from 1969 to 2018. Stream flows typically peak in April and May, due to snowmelt, and then gradually recede. The peak flows can also occur from June to August due to significant rainfall events. The distribution of monthly mean flows for Grande Prairie Creek (WSC 07GE003), based on 44 years of data, is presented in **Figure III.2**. **Figure III.3** presents the instantaneous peak flow events for the recorded period.

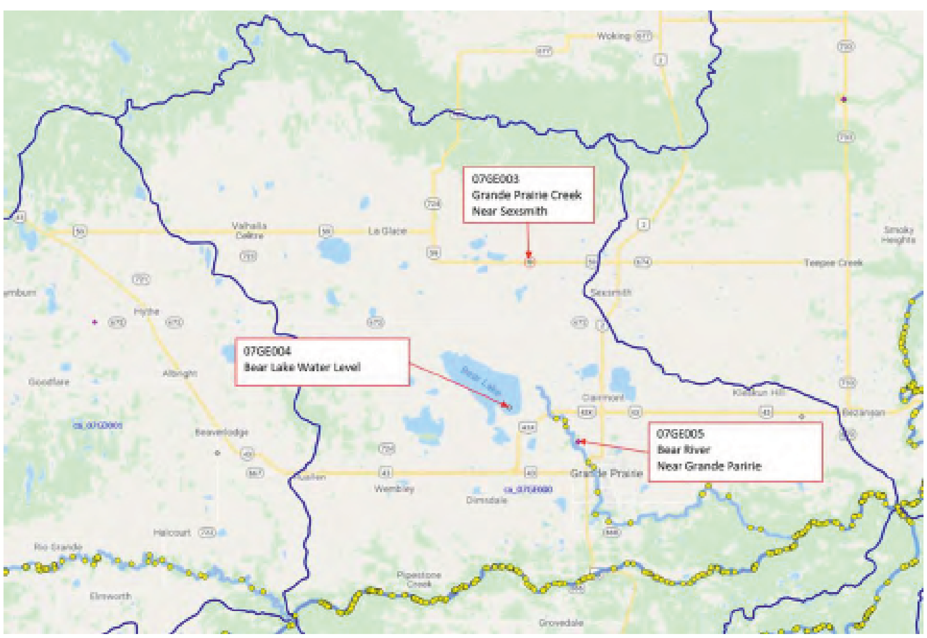


Figure III.1 Locations of Water Survey Canada Measuring Stations

Table III.1 Stream Flow and Lake Level Monitoring Station Operated by Water Survey of Canada

Station	Years	ID	N	E	Type	Area (km²)
Grande Prairie Creek Near Sexsmith	1969 to 2019	07GE003	55°22'28"	118°54'58"	Flow and Level	140
Bear River Near Grande Prairie	1983 to 1987	07GE005	55°12'00"	118°50'08"	Flow	1,510
Bear Lake Near Clairmont	1967 to 2009	07GE004	55°14'00"	118°57'00"	Level	1,190

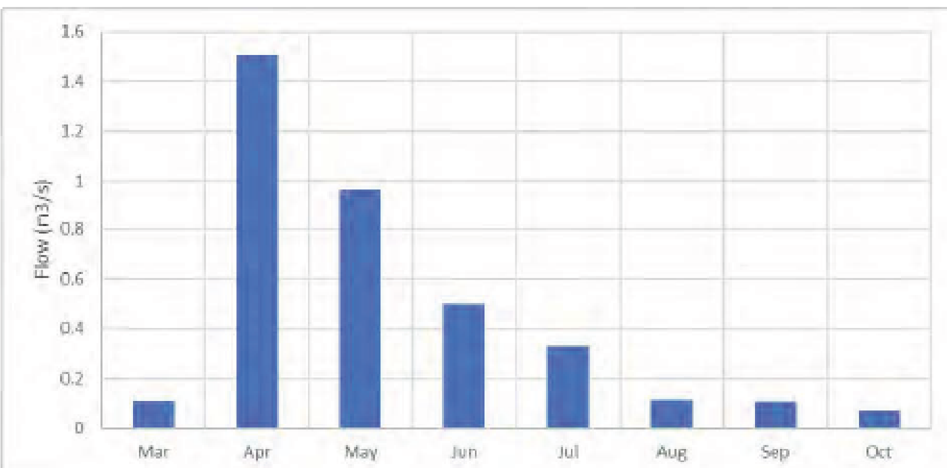


Figure III.2 Grande Prairie Creek (WSC 07GE003) Monthly Flow Distribution

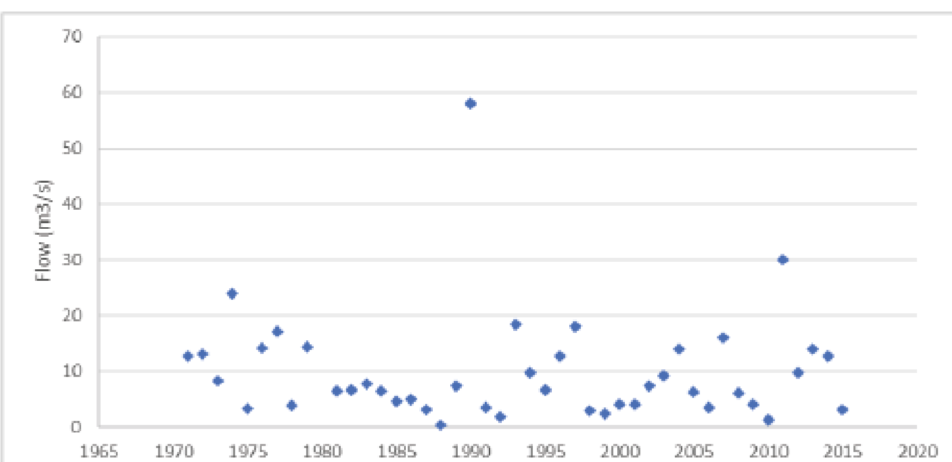


Figure III.3 Grande Prairie Creek (WSC 07GE003) Instantaneous Peak Flows

Recorded fluctuations of the Bear Lake water level over the record period of 1960 to 2009 ranged from El. 662.80 m to 665.80 m with the highest elevation recorded in 1974. An assessment of the rating curve of the reservoir was carried out based on the water level record at WSC 07GE004 and the discharge records at WSC 07GE005 and 07GE003 for the four years of concurrent records for the period between 1983 and

1986. The hydrometric data and the results of the analyses are presented in **Figure III.4**. The reconstituted rating curve, which assumes conservatively that the discharge is free of backwater, indicated that the maximum discharge water level from the lake was of around 19 m³/s.

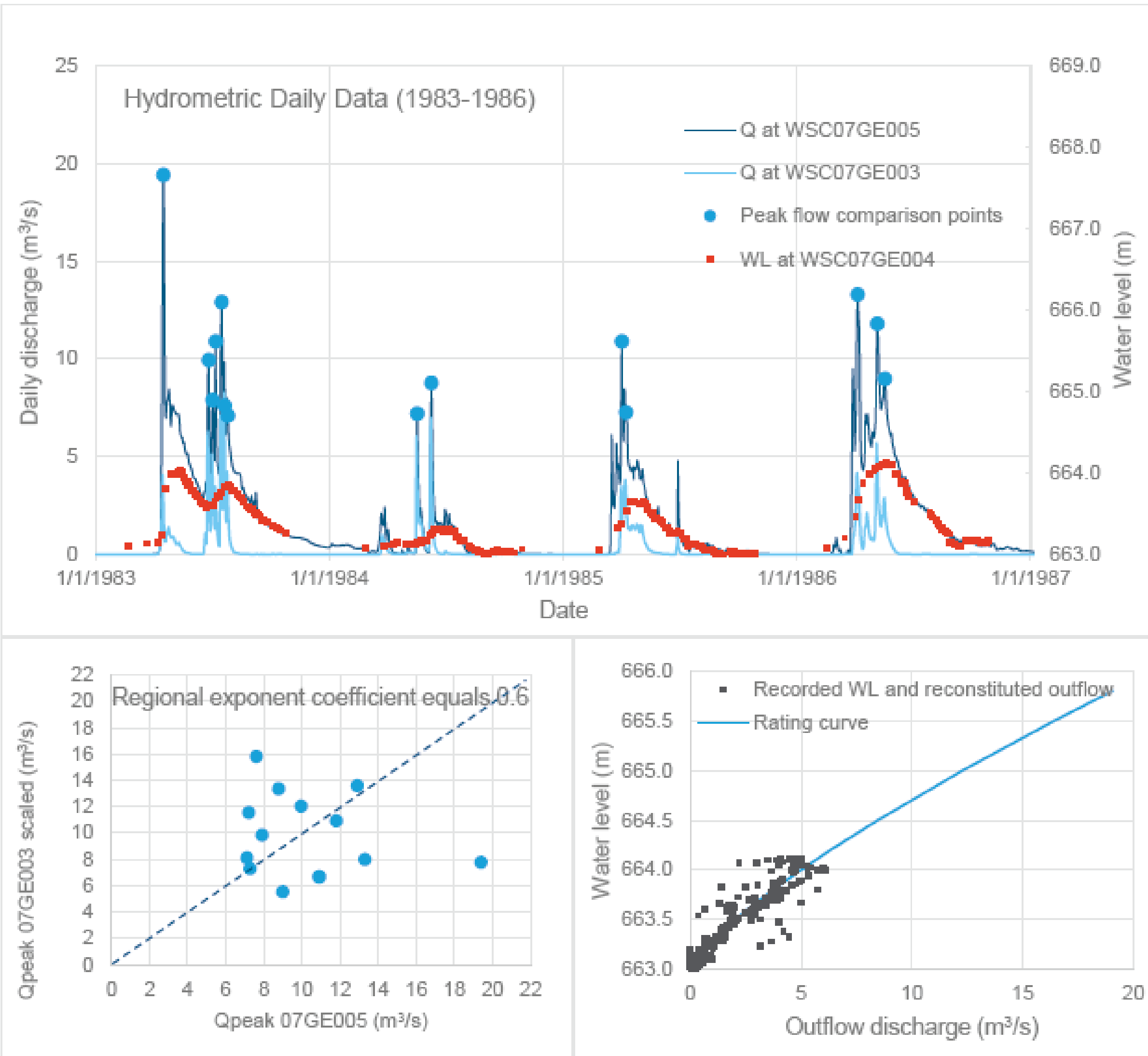


Figure III.4 Hydrometric Data and Bear Lake Rating Curve Assessment

The form of the regional equation for transposition of the peak flow downstream of Bear Lake is as follows:

$$Qtransposed = Qinitial \left(\frac{Area\ transposed\ watershed}{Area\ inital\ watershed}\right)^{Regional\ exponent\ coefficient}$$

The peak discharge at WSC 07GE003 was scaled for the entire watershed downstream of Bear Lake to the Bear River Reservoir (140 km² at WSC 07GE003 and 422 km² in total) using a regional equation. The regional exponent coefficient of the equation was determined based on the recorded peak discharges at WSC 07GE005 and 07GE003 for the period 1983-1986 as shown in **Figure III.4**. A coefficient of 0.6 was found to produce the best transposition of peak discharges between watersheds (bottom left chart on **Figure III.4**).

Comparison of the available four years of flow data (1983 to 1986) between the Bear River at the Bear River Reservoir and the Grande Prairie Creek are shown in **Figures III.5** through **III.8**. As noted in the figures, the peak flows of the two stations match with a time difference of approximately one day. Moreover, the contribution of the Bear Lake outflows and the Grande Prairie Creek to the hydrograph at Bear River Reservoir are clearly identifiable. The difference of the two hydrographs, after scaling the flows recorded at WSC 07EG003 to the intermediate watershed down to the Bear River Reservoir, corresponds to the outflows of the Bear Lake.

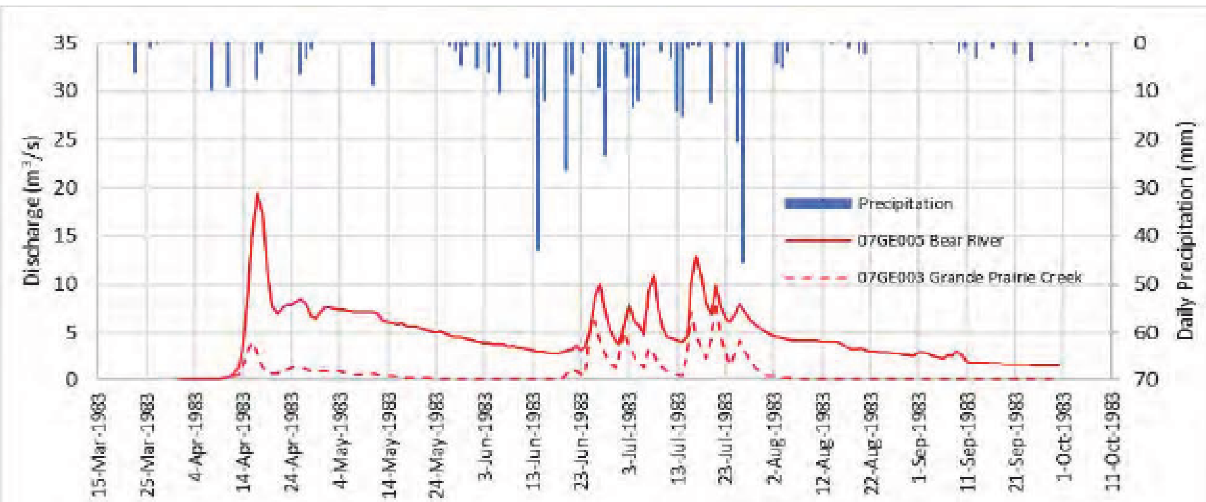


Figure III.5 1983 Bear River-Grande Prairie Creek Recorded Flow and Grande Prairie Airport Precipitation Data

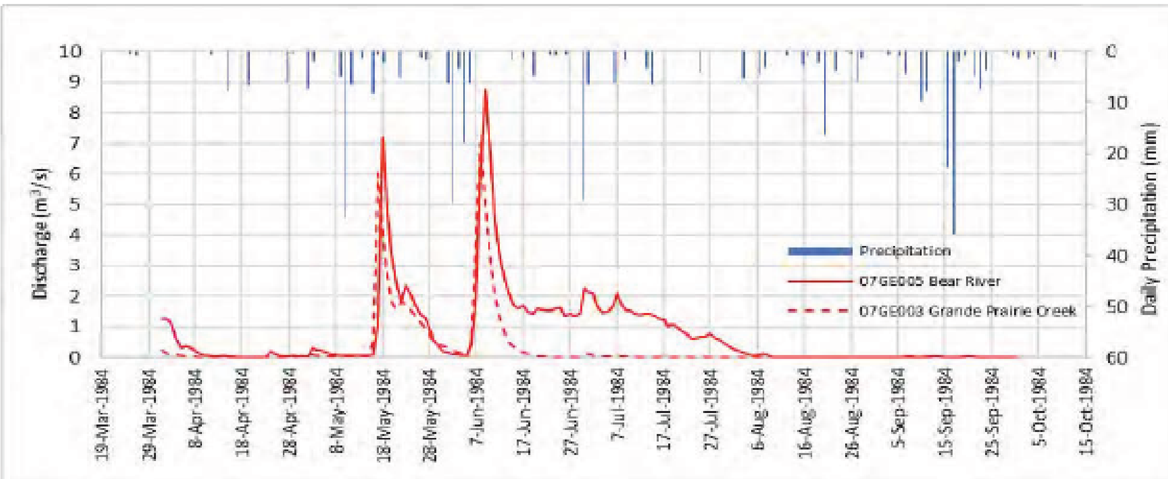


Figure III.6 1984 Bear River-Grande Prairie Creek Recorded Flow and Grande Prairie Airport Precipitation Data

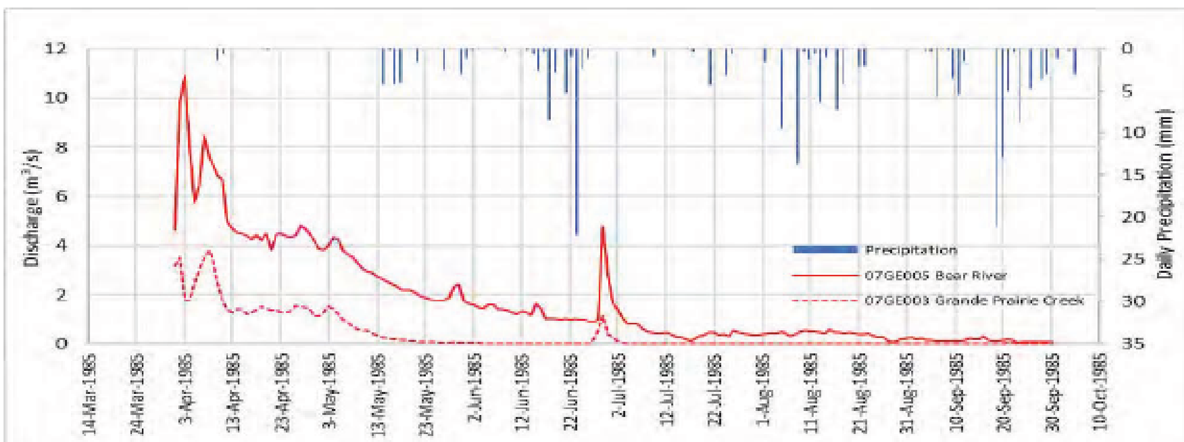


Figure III.7 1985 Bear River-Grande Prairie Creek Recorded Flow and Grande Prairie Airport Precipitation Data

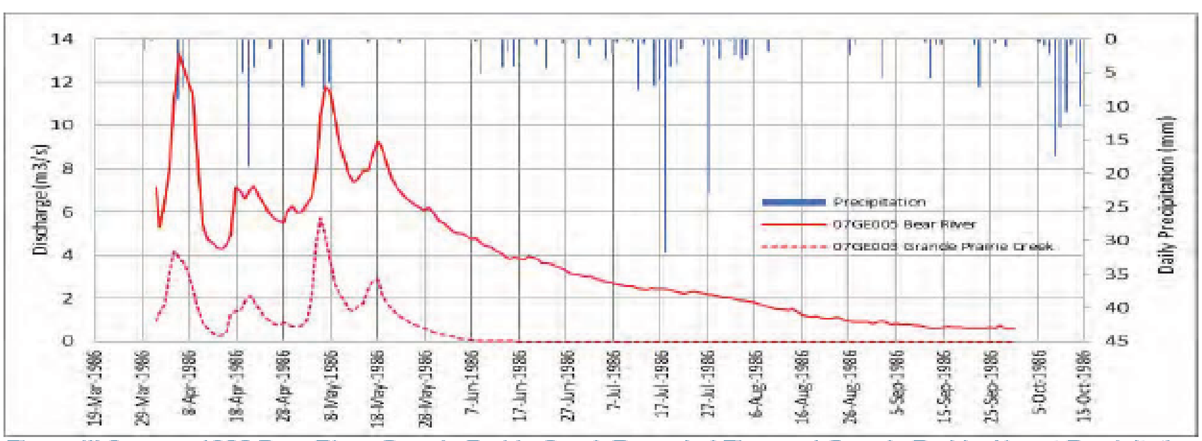


Figure III.8 1986 Bear River-Grande Prairie Creek Recorded Flow and Grande Prairie Airport Precipitation Data

3 PMF Review

The 2014 DSR estimated the Probable Maximum Flood (PMF) for the Bear River Reservoir inflow as 750 m^3/s. The study used the Creager Diagram in Alberta Transportation Guidelines on Extreme Flood Analysis (AT 2004). The current PMF estimate review used the same widely used flood envelope diagram of Creager for the peak discharge against drainage area. Using this curve, for the total drainage area of 1,566 km^2, and C value of 20, the PMF is estimated to be 1,566 m^3/s. Assuming 50% attenuation of the PMF within the Bear Lake, the estimated PMF to the reservoir is 783 m^3/s.

The 2014 DSR estimated the 24-hour point Probable Maximum Precipitation (PMP) for the Bear River using Hopkinson (1999) and Taylor and Hogg (2006) with a point PMP of 466 and 460 mm, respectively. The area adjusted 24-hour PMP for the project was estimated at 210 mm. Review of these PMP values was conducted using a statistical method proposed by Hershfield as stated in the Alberta Transportation manual. The method is based on the sample mean and sample standard deviation of the annual maximum precipitation sample and a multiplication factor applied to the standard deviation to obtain the probable maximum precipitation. The formula to estimate the PMP is:

$$PMP = Pm + KS$$

Where:

Pm	is the mean value of recorded annual maxima for that duration
S	is their standard deviation
K	is a factor usually in the range of 15 to 25

The PMP estimated for the project area, using K value of 22, is 445 mm which is close to the 2014 DSR estimates. Considering the uncertainties involved around estimation of PMP and PMF and the minor difference between estimates, the 2014 DSR PMF is applied for the current study.

4 Frequency Analysis

The inflow estimates to the Bear River Reservoir for the various return periods were based on the long-term Grande Prairie Creek data. Standard statistical methods were used in the analysis to derive long-term extremes and probability of occurrence of extreme events from theoretical probability distributions. Flood frequency analysis on the historical daily annual maximum flow data was performed with the HYFRAN-PLUS software. Numerical tests were performed using an automated spreadsheet developed by the City of Calgary. Nine different distributions (Normal, Lognormal, Exponential, Pearson III, Log Pearson III, Gumbel, GEV, Weibull, and Gamma) were tested for fitting the statistical sample. The Lognormal III distribution was the best fit for the station based on numerical goodness of fit (Anderson-Darling, Kolmogorov-Smirnov, and Least Square Ranking) tests.

The following assumptions are made to derive the inflows to the reservoir:

- The various return period flows of the Grande Prairie creek are upscaled using a simple ratio of the gauged station flows.

- Bear Lake has significant influence on the Bear River flow. For flood events up to the 1,000-year event, the contribution of the Bear River at the confluence with Grande Prairie Creek is estimated based on the Bear Lake water level data and comparison of Bear River and Grande Prairie Creek hydrographs. As per this evaluation, the contribution is estimated at 20 m^3/s.

- Previous studies noted that part of the Grande Prairie Creek flow at the confluence with the Bear River flow is reversed to the Bear Lake. For this study, the flow reversal to the Bear Lake for flood events up to the 1,000-year flow is estimated to be 10%.

The result was upscaled to the watershed area of Bear River Reservoir with the regional equation applying a regional exponent coefficient of 0.6 as presented in Section 2. Summary of the analysis on the annual daily maximum flows is presented in **Table III.2**.

Table III.2 Estimated Bear River Reservoir Maximum Annual Daily Inflows

Return Period	Daily Peak Flows
2	33
5	46
10	56
20	68
50	85
100	100
500	141
1,000	162

The daily flows of the Bear River gauged data at Grande Prairie (1983 to 1986) were reviewed for the observed hydrographs. The review confirmed that the unit hydrograph considered in the 2014 DSR is representative of the observed hydrographs. This unit hydrograph from the 2014 DSR was used to scale up the various flood events for this study. **Figure III.9** presents the flood hydrograph into the Bear River Reservoir.

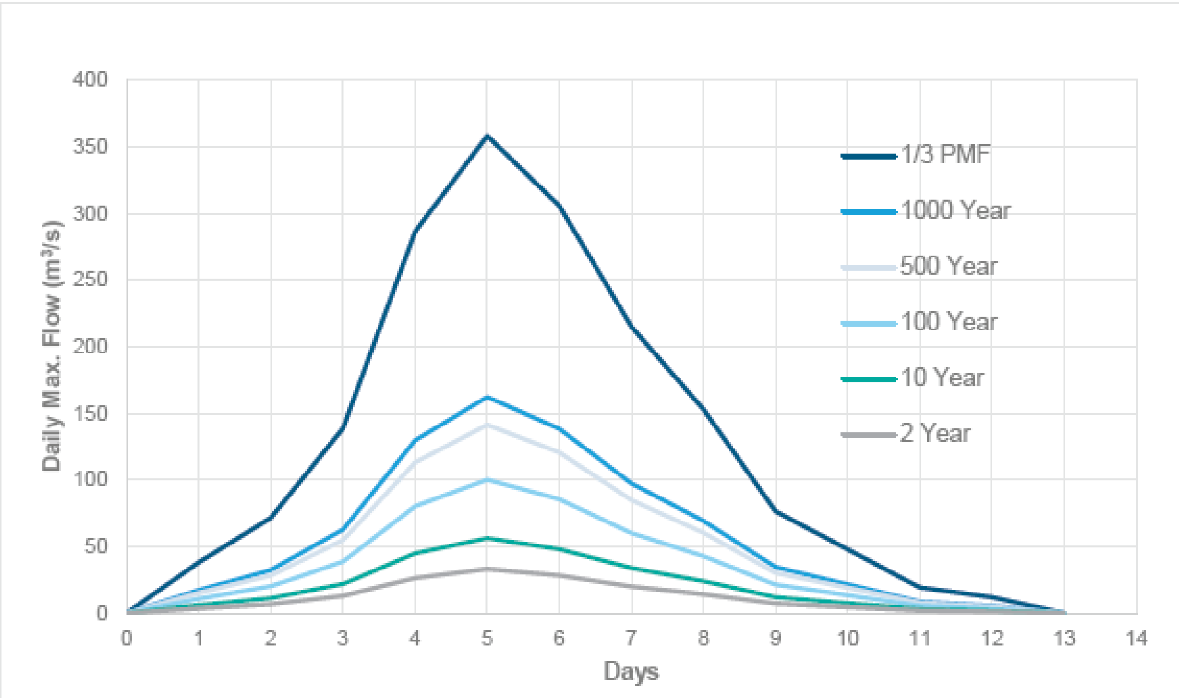


Figure III.9 Flood Hydrograph into Bear River Reservoir

5 References

Alberta Transportation (AT), 2004. *Guidelines on Extreme Flood Analysis*. Prepared for Transportation and Civil Engineering Division. November 2004.

Golder Associates (Golder), 2014. *Dam Safety Review – Bear River Control Structure*. Report Number 12-1326-0062. May 13, 2014.

Northwest Hydraulic Consultants (NHC), 2007. *City of Grande Prairie Flood Risk Mapping Study*. Prepared for Alberta Environment. March 2007.

Appendix IV

Environmental and Cultural Values Consequence Classification

SNC·LAVALIN
Environment & Geoscience
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780.436.9400

To:	City of Grande Prairie	**Date:**	December 21, 2020
From:	SNC-Lavalin Inc.	**Project.:**	676065
Subject:	**Environmental and Cultural Values Consequence Classification Rating for the Dam Safety Review of the Bear River Control Structure, Grande Prairie, Alberta**		

1 Introduction

SNC-Lavalin Inc. (SNC-Lavalin) was retained by the City of Grande Prairie (the City) to complete a Dam Safety Review (DSR) for the Bear River Control Structure (BRCS), located in Grande Prairie, Alberta. The BRCS is located within the City of Grande Prairie on the Bear River at Muskoseepi Park, as depicted in **Figure IV.1**:

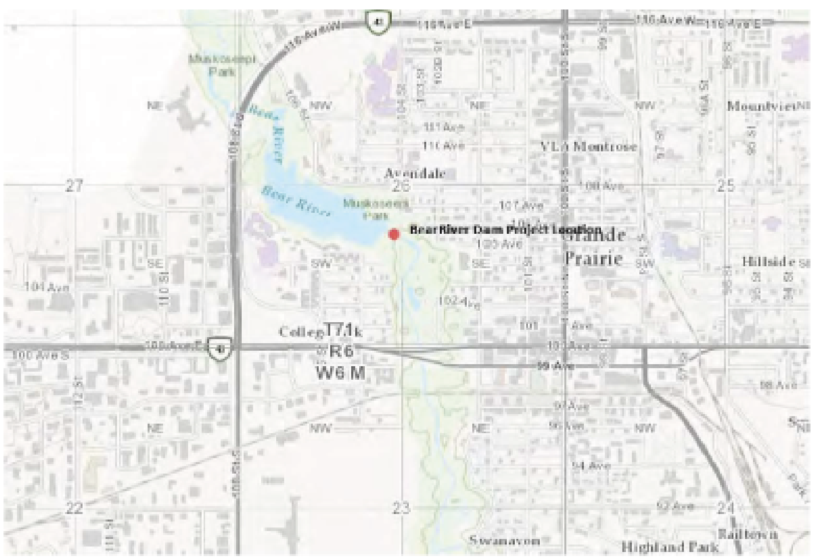

Figure IV.1 Bear River Control Structure location within the City of Grande Prairie, Alberta.

The Bear River reservoir is controlled by the BRCS, which was built in 1948 and reconstructed in 1975-1976. The BRCS is operated by the City of Grande Prairie and is currently used for recreation and erosion control purposes. Releases from the reservoir are controlled by a gated spillway consisting of a cast-in-place reinforced concrete chute with two gated bays equipped with manually operated radial gates (last replaced in 2008).

SNC-Lavalin is currently completing a formal DSR, which is required for the BRCS every seven years. The principal objective of the DSR is to evaluate the safety of the dam and associated structures within the framework of the regulatory requirements outlined in Part 6 of the provincial Water (Ministerial) Regulation 205/1998 under the *Water Act*, including the Alberta Dam and Canal Safety Directive (AEP 2018), and the best practices from the Canadian Dam Association (CDA) Dam Safety Guidelines (2007, revised 2013) and accompanying Bulletins.

As part of the scope of the DSR, SNC-Lavalin is completing a consequence classification under the Consequence Classification Ratings for Dams and Canals (AEP 2019) for the BRCS.

2 Objectives and Scope

This letter provides the results of the evaluation of the incremental consequences of flooding and a dam breach in the Bear River in the following possible flood scenarios:

› 100-year flood without dam breach/failure;

› 1,000-year flood without dam breach/failure; and

› One third Probable Maximum Flood (PMF) plus 1,000-year flood with and without a dam breach/failure.

The evaluation focusses on the environmental and cultural values for the classification rating, which includes assessing the loss or damage to the following elements:

› Fish and fish habitat;

› Wildlife and wildlife habitat;

› Rare or endangered species (Species at risk);

› Unique landscapes;

› Sites of cultural significance; and

› Possibility of restoration or compensation of losses.

3 Study Area

SNC-Lavalin conducted a detailed hydrotechnical analysis to evaluate detailed breach inundation study conducted for the BRCS for each flood scenario, as well as a dam failure.

Each flood scenario would cause a considerable increase to the river velocity and volume. The increased flow rate and water volume under these flood scenarios would result in severe bank erosion/loss, loss of riparian areas, sedimentation downstream and possibly into the Wapiti River. The impacts would be greater immediately downstream of the BRCS, with a reduction of impacts as the distance from the breach increases. It is estimated that the flood events would likely occur at periods of higher river levels and volumes, such as spring during freshet.

The anticipated downstream impacts on Bear River from the increased flow and water levels resulting from these flood events were modelled up to approximately 14 km downstream of the BRCS, south of the Grande Prairie Golf and Country Club in the Wedgewood community adjacent to the southern City limits. This portion of Bear River is considered the study area for the assessment of incremental environmental and cultural impacts.

4 Environmental Setting

The study area outlined in **Section 3** is located within the Parkland Natural Region of Alberta, specifically the Peace River Parkland Subregion, which is defined by gently rolling plains and steep, south-facing slopes along the Peace River. This subregion is characterized by cool winters and drier summers when compared to other subregions within the Parkland Natural Region. On a regional level, the mean average temperature (MAT) is +1.5°C and the mean average precipitation (MAP) is 450 mm. Agriculture and petroleum exploration and development are extensive throughout the subregion (NRC 2006).

Bear River is a fish-bearing tributary to the Wapiti River and is part of the smoky/Wapiti sub-basin of the Peace River Watershed. The river originates in Bear Lake approximately 10 km northwest of the City and generally runs north to south with an eastward bend at the southern edge of the City. The drainage area is approximately 1,500 km^2 (NHC 2007).

The study area consists mainly of a riverine valley situated within a developed urban environment that includes residential, recreational, natural, and industrial land uses. The City, and adjacent portions of the study area to the south, are considered part of Alberta White Areas, and are not located within a Key Wildlife and Biodiversity Zone. The nearest Key Wildlife and Biodiversity zone is located east of the study area further downstream on Bear River, east of Resources Road (AEP 2020a).

The BRCS is located on Bear River within the urban limits close to the downtown core, within Muskoseepi Park, which contains over 1,100 acres of park space and includes amenities such as walking trails, outdoor activities, and various attractions. The park is intended for day use and the BRCS, its reservoir, and downstream areas include a fishing pond (not hydraulically connected to Bear River), walking/bicycle paths, museums, and sports facilities. The remainder of the river valley downstream contains various natural paths and is bounded by residential developments, sports facilities, and the Aquatera Wastewater Treatment Plant and the Grande Prairie Golf and Country Club at the south end of the study area. These facilities are not anticipated to be affected by any potential flood event.

Muskoseepi Park is consistent with urban park environments characterized by natural riparian habitats and seeded grassed areas with various tree species. Portions of the park are maintained by the City. Riparian areas consisting of trees, shrubs (likely willow species), and grasses can be found on the banks of Bear River in immediate downstream areas. Areas further downstream contain larger riparian zones characterized by more abundant trees and no maintained grassed areas.

A query of the Fish and Wildlife Management Information system (FWMIS) indicates records for both fish and wildlife within the estimated failure area of the BRCS. The species records from the FWMIS query are described in **Sections 4.1** and **4.2** (AEP 2020b). Records from the Alberta Conservation Information Management System (ACIMS) for Township 071 and Range 06 (W6M) indicate no sensitive and non-sensitive element occurrences have been identified within the study area (AEP 2020c).

The study area contains several Environmental Sensitive Areas (ESA) located along Bear River. ESAs are defined as areas that are important to the long-term maintenance of biological diversity, physical landscape, and/or other natural processes, both locally and within a larger spatial context. The ESAs and their overall value are scored using multiple criteria for a given location, such as presence of focal species and their habitat; unique, rare habitats and landforms; ecological integrity; and finally, contributions to water quality and quantity (Fiera 2014). These criteria are applied at the quarter section level.

Within the study area, ESA scores were compiled for affected quarter sections. Scores ranged from 0.085 to 0.211. The quarter sections with the highest scores are located within the east-west portion of the river west of the Grande Prairie Golf and Country Club at the south end of the City limits. These two quarter sections correspond to the widest riparian zones in the study area.

4.1 Fisheries

Bear River is a Class C Waterbody with a Restricted Activity Period (RAP) between April 16 and July 15 (GOA 2006). Fish species located within the study area, as per FWMIS, are described in **Table IV.1** below (AEP 2020b).

Table IV.1 Fish species FWMIS records within the study area

Common Name	Scientific Name	Inventory Type	Spawning Season[1,2]	Spawning Habitat[1,2]
Brook stickleback	*Culaea inconstans*	Native	Late spring/early summer	Areas with aquatic vegetation
Goldfish	*Carassius auratus*	Exotic/Alien	n/a	n/a
Longnose sucker	*Catostomus catostomus*	Native	Late spring	Creeks and beach spawning (in lakes)
Slimy sculpin	*Cottus cognatus*	Native	Late spring	Underside of small ledges or rocks in streams, rivers, and lakes
White sucker	*Catostomus commersoni*	Native	Late spring	Creeks and beach spawning (in lakes)
Yellow perch	*Pesca flavescens*	Native and stocked inventory	Early spring	Shallow, sheltered, vegetated areas in tributaries
Rainbow trout	*Oncorhynchus mykiss*	Stocked inventory	Spring (stocked spawn earlier than native populations)	Running water, small tributaries of rivers or inlets of lakes, usually over fine gravel
Walleye	*Stizostedion vitreum*	Stocked inventory	Early spring	Streams or lake bottoms; moderate- to fast-running water or over rocky shoals in lakes

Notes:

[1] Joynt, A. and Sullivan, M.G., 2003. Fish of Alberta. Lonepine Publishing. Edmonton, AB. 176 pp.

[2] Nelson J.S., and Paetz, M.J., 1992. The Fishes of Alberta, Second Edition. The University of Alberta Press. Edmonton, AB. 465 pp.

The search radius of the FWMIS report includes the reservoir, as well as reaches of Bear River both upstream and downstream of the reservoir up to the extents of the study area. The fish habitat available consists of deeper lentic habitat within the reservoir upstream of the BRCS, and shallower lotic habitats characteristic of a meandering river downstream extending to the extents of the study area. Adequate habitat, including spawning, rearing, and overwintering, exists within the reservoir and the Bear River system to support the native fish populations identified (brook stickleback, slimy sculpin, white sucker, longnose sucker, and yellow perch). The study area includes Muskoseepi Pond, which is not hydraulically connected to Bear River. The pond is stocked seasonally by Alberta Fish and Wildlife. Stocked inventory (rainbow trout and walleye), as well as invasive goldfish, appear to be limited to the pond and are not found within the Bear River system.

4.2 Wildlife

Wildlife species located within the study area, as per FWMIS, are described in **Table IV.2** below (AEP 2020b).

Table IV.2 Wildlife species FWMIS records within the study area

Common Name	Scientific Name	Habitat Type[1,2,3,4,5]	Breeding Season
Barred owl	*Strix varia*	Mature coniferous and mixedwood forests, often in riparian areas; nesting in trees.	Late winter
Boreal toad	*Anaxyrus boreas*	Various aquatic habitats (breeding), terrestrial wetland habitats (non-breeding); prefers dense vegetation cover.	Spring
Northern long-eared bat	*Myotis septentrionalis*	Winter hibernacula in caves or abandoned mines; summer roosting in tree cavities and in tree cavities of over-mature forest stands.	Late summer or early fall
Red-sided garter snake	*Thamnophis sirtalis*	Tolerates a verity of habitats including forests, wetlands, shrublands, fields and rocky areas; Requires high-quality hiberanacula sheltered and/or deep below frost line.	Immediately after winter, early spring and late summer immediately prior to hibernation.
Short-eared owl	*Asio flammeus*	Grasslands, meadows and cleared forests; ground nests	Early spring
Trumpeter swan	*Cygnus buccinator*	Small to medium sized shallow isolated lakes with well developed emergent and submergent plant communities; breeding habitat freshwater lakes, marshes, ponds and rivers with sufficient room for takeoff, low human disturbance, islands for nesting sites.	Spring
Wandering garter snake	*Thamnophis elegans*	Tolerates a verity of habitats including forests, wetlands, shrublands, fields and rocky areas; hiberanacula in mammal burrows, natural crevices, talus slopes or anthropogenic structures beneath the frost line.	Late spring

Notes:
[1] Semenchuk, G.P., 1992. The Atlas of Breeding Birds of Alberta. Federation of Alberta Naturalists. Edmonton, Alberta. 391 pp.
[2] Fisher, C.C. and Acorn, J. 1998. Birds of Alberta. Lonepine Publishing. Edmonton, Alberta. 384 pp.
[3] Cornell Lab of Ornithology. 2020. Birds of the World online database. Cornell University. Ithaca, New York, USA.
[4] Caceres, M.C. and Pybus, M.J. 1997. Status of the Northern Long-eared Bat (Myotis septentrionalis) in Alberta. Alberta Environmental Protection, Wildlife Management Division, Wildlife Status Report No. 3, Edmonton, Alberta. 19 pp.
[5] Wind, E.I. and Dupuis, L.A. 2002. COSEWIC Status Report on the Western Toad Bufo boreas in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario. 31 pp.
[6] Clayton, K.M. 2000. Status of the Short-eared Owl (Asio flammeus) in Alberta. Alberta Environmental Protection, Wildlife Management Division, Wildlife Status Report No. 28, Edmonton, Alberta. 21 pp.
[7] Crews D. 1983. Control of Male Sexual Behaviour in the Canadian Red-Sided Garter Snake. Hormones and Behaviour in Higher Vertebrates. Springer-Verlag Berlin Heidelberg.
[8] Smith, P.A. 2013. Status of the Trumpeter swan (Cygnus buccinator) in Alberta. Alberta Environment and Sustainable Resource Development Alberta Conservation Association, Wildlife Status Report No. 26 (Update 2013), Edmonton, Alberta. 55 pp.

Muskoseepi Park at the BRCS is maintained by the City and habitat largely consists of open grassed areas dotted by small- to moderate-sized deciduous and coniferous tree stands. The reservoir upstream of the BRCS, and Bear River within the Park, are bordered by a narrow riparian area consisting mainly of willow trees, shrubs, and grasses, with wider riparian areas further downstream consisting of denser treed vegetation. Wildlife habitat in the study area supports amphibians, small mammals, and birds.

Habitat is suitable within the study area for Boreal toads and garter snake species both during breeding and non-breeding seasons. The habitat types are unlikely to support bat populations given the overall species rarity across Alberta and their reliance on mature forest habitats (Caceres and Pybus 1997).

The project location is within nesting zone B5 (GOC 2020), which has a regional nesting period between late April and late August. The study area, including Muskoseepi Park, contains adequate nesting habitat for many migratory and year-long resident bird populations. There is a designated Important Bird and Biodiversity Area (IBA) located to the west, north, and northwest of the City. The IBA (AB 107) is 1,308 km^2 and contains globally significant congregatory species and waterfowl concentrations, including Trumpeter swans (Bird Studies Canada and Nature Canada 2020). The IBA does not overlap with anticipated inundation locations and the study area.

Trumpeter swan habitat can be found at multiple lakes and waterbodies in the Grande Prairie area and have been observed staging and foraging in Muskoseepi Park and areas along the study area. Due to low tolerance for human disturbance, swans are likely to utilize more isolated portions of the study area as nesting sites. Nests are typically not located on upland areas but near the shore or within the waterbody on mammal dens (e.g., beaver lodges, muskrat houses), floating vegetation mats, or small islands (Smith 2013).

Habitat in the study area, especially in the downstream portions with larger riparian areas, is suitable for owl populations and other birds of prey for nesting, rearing young, and foraging.

4.3 Species at Risk

The federal and provincial protection status for the fish and wildlife species identified in the FWMIS search (**Table IV.1** and **Table IV.2**) are listed in **Table IV.3** and **Table IV.4** below:

Table IV.3 Federal and provincial status for fish species FWMIS records within the study area

Common Name	Scientific Name	COSEWIC Status[1]	Listed on SARA[2] Sch. 1	SARA Status	AB Status[3]
Brook stickleback	*Culaea inconstans*	No status	No	No status	Secure
Goldfish	*Carassius auratus*	No status	No	No status	Exotic/Alien
Longnose sucker	*Catostomus catostomus*	No status	No	No status	Secure
Slimy sculpin	*Cottus cognatus*	No status	No	No status	Secure
White sucker	*Catostomus commersoni*	No status	No	No status	Secure
Yellow perch (Stocked and native)	*Pesca flavescens*	No status	No	No status	Secure
Rainbow trout (Stocked)[4]	*Oncorhynchus mykiss*	No status	No	No status	Secure
Walleye (Stocked)	*Stizostedion vitreum*	No status	No	No status	Secure

Notes:
[1] Committee on the Status of Endangered Wildlife in Canada as per the Species at Risk Registry (GOC 2020b)
[2] Species at Risk Act as per the Species at Risk Registry (GOC 2020b)
[3] General Status of Alberta's Wild Species (AEP 2017)
[4] Stocked or introduced stocks of Rainbow trout are Secure in Alberta. Federal status for Rainbow trout is Endangered and is listed under SARA Schedule 1, however, this is applicable to native stocks in the Athabasca River only, and this status is not applicable.

Table IV.4 Federal and provincial status for wildlife species FWMIS records within the study area

Common Name	Scientific Name	COSEWIC Status[1]	Listed on SARA[2] Sch. 1	SARA Status	AB Status[3]
Barred owl	*Strix varia*	No status	No	No status	Sensitive
Boreal toad	*Anaxyrus boreas*	No status	No	No status	Sensitive
Northern long-eared bat	*Myotis septentrionalis*	No status	No	No status	May Be at Risk
Red-sided garter snake	*Thamnophis sirtalis*	No status	No	No status	Sensitive
Short-eared owl	*Asio flammeus*	Special Concern	Yes	Special Concern	May Be at Risk
Trumpeter swan	*Cygnus buccinator*	Not at Risk	No	Not at Risk	Sensitive
Wandering garter snake	*Thamnophis elegans*	No status	No	No status	Sensitive

Notes:
[1] Committee on the Status of Endangered Wildlife in Canada as per the Species at Risk Registry (GC 2020b)
[2] Species at Risk Act as per the Species at Risk Registry (GC 2020b)
[3] General Status of Alberta's Wild Species (AEP 2017)

None of the native or stocked fish species encountered within the study area are protected under federal legislation and all are considered secure at a provincial level.

Of the wildlife species identified, short-eared owl is considered Special Concern under COSEWIC and SARA. Short-eared owls nest in grassland habitats where small mammal prey is abundant (Clayton 2000). This type of habitat may be present in the upland areas adjacent to the Bear River. None of the other wildlife species identified have federally protected status; however, all species identified have Sensitive to May be at Risk statuses under the Alberta *Wildlife Act*. Trumpeter swans are of significant consideration as they make abundant use of the Grande Prairie area during migration and breeding.

5 Heritage and Cultural Setting

Areas of heritage and cultural significance are located directly downstream of the BRCS and within Muskoseepi Park further downstream along Bear River within the study area. Based on a review of the Alberta Listing of Historical Resources, the study area has a historical resource value (HRV) of five (5), which designates a high potential to contain a historic resource. In these areas, the primary historic resource categories are archaeological and palaeontological (GOA 2020).

Muskoseepi Park was opened in 1986 for land preservation and to offer a variety of activities for residents and tourists of the Grande Prairie area.

The park contains the following amenities and facilities:

› Sporting facilities, including basketball courts, horseshoe pitches, a skateboard park, outdoor pool, and tennis court;

› Recreation areas including Muskoseepi Pond (summer fishing and winter skating), playgrounds, climbing wall, lawn bowling, a spray park, and a disc golf course;

› Natural areas for day use including natural and paved hiking trails;

› Public use buildings including an amphitheatre and available room rentals; and

› The Ernie Radbourne Pavilion, which is the central administrative building for the park and provides meeting and event spaces.

The Grande Prairie Museum and Heritage Village is also located within the park. The museum opened in 1970 with a focus on preserving the pioneer history of the Grande Prairie area. The museum's collection contains approximately 55,000 items. The museum has an adjacent heritage village open annually during the spring to fall. The village offers various structures, replicas, and equipment with heritage significance (City of Grande Prairie 2020).

The South Peace Regional Archives (SPRA) are also located within the museum complex at the park. The SPRA was established in 2000 and is used as a local genealogical and historical information source for the area. The SPRA acquires, preserves, and curates records in various formats including digitized documents, photographs, audio recordings, and films/video recordings, which are made available for public use. The SPRA also has a number of publications related to local history, and hosts events periodically (City of Grande Prairie 2020).

6 Anticipated Impacts from Floods and Dam Failure

A 1:100 and 1:1000 flood year, along with PMF events, would cause a significant increase in downstream water velocity, flow volume, and water level. A dam breach at the same time would cause further increases to these parameters, although the incremental increase in water velocity, flow volume, and water level is small compared to the increase caused by the significant flood events (compared to background flow volumes). For all modelled scenarios, flood effects are most significant immediately downstream of the dam, and gradually attenuate further downstream. These breaches could be catastrophic for the riverine and riparian ecosystems that are located downstream of the dam. It is also likely that impacts to the upstream reservoir environment would also occur during a breach, as reductions in water levels may cause additional mortality to aquatic species. For the purposes of this study, it is assumed that a dam breach would not release all the sediment built up behind the dam; most of the accumulated sediment would remain in the reservoir.

6.1 Fisheries

All flood events would cause a considerable increase to sediment loads due to erosion from increased water flows and velocity, which would be amplified in the event of a dam breach. These increases are expected to be greatest immediately downstream of the dam until they gradually return to near background levels up to approximately 8.5 km downstream. The sediment plume caused by the floodwaters, however, is likely to continue even farther down Bear River, and the increased turbidity may be transported into the Wapiti River. Although some sediment will gradually drop out of the water column and come to rest on the bottom of the river, the majority of the sediment will remain suspended until water velocities are reduced in a lentic or slow-moving river environment.

These increased sediment loads are known to cause significant impacts to both juvenile and adult fish (e.g., egg destruction, upheaval, and suffocation) if it were to occur during a spawning period (Fernandes et al. 2016). The increased sediment loads would likely also cover or wash-out spawning habitat (removing small stones and rooted vegetation), making it unavailable for future spawning seasons as well. These sediment loads also have the potential to impact adult fish, as the increased turbidity can potentially suffocate fish if they cannot find refuge in other locations. Mortality may also occur in smaller fish which may also not be able to withstand the increased flows and could be washed downstream and/or stranded on land (Young et al. 2011, Cushman 1985).

All floods events, and to a larger extent a dam failure, are expected to cause Bear River to overtop its banks in some locations. This could cause an increase in the load of deleterious substances to the water, as contaminants on land may be washed into the river. These overtopped banks may also cause fish to be stranded on shore when water levels return to pre-flood levels. A dam failure would also cause a loss in upstream fish habitat if the reservoir was partially or completely drained, but this would not occur in a flood-only scenario. A dam breach would also impact the nearby Muskoseepi Pond. Fish in the pond might also be affected by increased sedimentation but may also be released into the river or stranded on land. A dam breach would also cause a loss of eggs or fish larvae in the near shore areas of the Bear River Reservoir if the reservoir was to drain as a result of the dam failure.

6.2 Wildlife

All flood events and a dam rupture would cause an increase in water levels. Adult birds are generally not at risk for flooding, as they will be capable of relocation. However, any nests or eggs that are present on the shorelines or near-shore areas may be washed out and likely lost. Juvenile birds or nestlings that are not yet fledged from a nest may also be impacted by flood waters. Amphibian and reptile species are likely to be able to move away from the high-water levels, but some individuals may be impacted if they are unable to escape from the flood waters. Large mammals should have no issues moving away from flood waters, but small burrowing mammals may be trapped and drowned if their burrows are flooded. The overtop of the riverbanks and associated bank erosion could cause habitat loss.

6.3 Species at Risk

There are no expected impacts to aquatic species at risk, as species with federal or provincial status are not present within the study area. Short-eared owls are the only federally protected species present within the study area, and the adult birds are unlikely to be impacted by flood or dam failures. However, any nests or eggs of these short-eared owls that happen to be located within the flood limits are likely to be lost. This is likely only during a dam failure, where grassland areas adjacent to the Bear River may be temporarily flooded by high-water levels. Provincially, statuses for wildlife species identified in the study area range between Sensitive and May be at Risk.

6.4 Heritage and Cultural Sites

As all flood events and a dam rupture would cause an increase in water levels, impacts to sites of cultural and heritage significance adjacent to or within the study area would be anticipated. Anticipated impacts would cause temporary flooding which may impact buildings and their contents. Erosion of riparian areas, or to the bed and banks of Bear River, may result in loss of terrain and any possible buried heritage resources.

6.5 Summary

A summary of the anticipated impacts from a flood event is presented in **Table IV.5**. The anticipated consequence classification rating for each environmental category (AEP 2019) and each flood event (with and without a dam breach) are presented in **Table IV.6**.

Table IV.5 Summary of anticipated impacts

Item	Anticipated impacts in the study area	Restoration Potential
Fisheries	Loss and damage to bed and bank of Bear River. Fish mortality (suffocation, burial, stranding, trauma and/or erosion of eggs and young downstream). Loss and damage of fish habitat (spawning, rearing, and overwintering) Deposition of deleterious substances from upland locations. Sedimentation downstream and possibly entering the Wapiti River.	Damages to bed and bank can be restored. Water quality impacts from sedimentation require natural attenuation.
Wildlife	Loss and damage to habitat in riparian zones within the impacted zone. Wildlife injury and/or mortality. Loss and damage to nests, dens, habitations.	Damages to habitat may be restored and natural attenuation can restore habitats over time.
Rare or endangered species	No impacts to fish species at risk. Possible impacts to sensitive species or species of special concern, especially nesting birds.	See above
Unique landscapes	Loss and damages to ESAs along Bear River, notably west of the Grande Prairie Golf and Country Club.	Damages to landscapes may be restored.
Sites of cultural or heritage significance	Flooding in lowlying parts of Muskoseepi Park and buildings. Damages to Muskoseepi Park amenities and buildings. Possible loss of historic resources. Damage or loss of records, exhibits, archives. Damage or loss to Muskoseepi Pond. Damages or loss of nature trails within riparian areas. Erosion damages to downstream infrastructure and facilities.	Buildings and museum artifacts/exhibits may be restored. Muskoseepi Pond can be restored and restocked. Nature trails can be repaired and/or relocated. Eroded areas may be candidates for restoration.

Table IV.6 Consequence Classification for each environmental category as a result of potential flood scenarios

Impact Category	1:100 Year Flood – No Dam Breach	1:1000 Year Flood – No Dam Breach	1/3 PMF and 1:1000 Year Flood – With Dam Breach
Fish and Fish Habitat	Significant	Significant	Low
Wildlife	Low	Low	Low
Species at Risk	Low	Low	Low
Unique Landscapes	Low	Low	Low
Sites of Cultural Significance	Low	Low	Low

7 Restoration and Compensation

Habitat restoration and compensation, if required, would be feasible after flooding cleanup; however, natural recovery may be more practical in isolated areas. Banks that are eroded by high-velocity flood water can be stabilized once water levels decrease. The removal of sediments that are washed downstream is likely not possible without additional environmental harm. Restoration or compensation in kind for losses and damages is highly possible within developed and easily accessible areas within the City. Depending on the level and location of damages or loss, and depending on future municipal or county planning developments, specialized habitat restoration plans may be required. Wildlife species, including fish, impacted by the flooding are likely to naturally recolonize the areas naturally over time, so long as sufficient habitat remains. For fish species, this can be accelerated by stocking efforts. In the event of a dam breach, it is possible that the previously isolated upstream and downstream populations may be able to reintegrate into a single population (Allen et al. 2016). Muskoseepi Pond may be restored and restocked.

Restoration of sites of cultural significance would be possible; however, some permanent loss of more sensitive items (e.g., paper archives, documents, exhibits, museum artifacts) is anticipated as a result of water damage in flooded buildings.

8 Conclusions

Environmental impacts as a result of flooding and/or dam breaches are expected to be low to significant in Bear River, especially immediately downstream with gradual attenuation of the effects as the flood moves downstream. The greatest impacts are expected in aquatic species, but a dam failure could also cause impacts to the near-shore environment (nesting birds, burrowing mammals, and their habitat) where the floodwaters overtop the banks and spread across upland areas. Short-term impacts to culturally significant buildings and sites are also anticipated immediately downstream of the dam.

9 Closure

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Engineering, Design and Project Management

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Appendix V

Wind Wave Analysis for Freeboard Assessment

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Memorandum

To:	City of Grande Prairie	**Date:**	February 23, 2021
From:	SNC-Lavalin Inc.	**Project.:**	676065
Subject:	**Wind Wave Analysis and Freeboard Assessment for Bear River Control Structure Dam Safety Review**		

1 Freeboard Criteria

According to the CDA 2007 DSG, the criteria to evaluate freeboard for dams are as follows:

- **Normal Freeboard:** No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1:1,000 year when the water level in the pond is at its maximum normal operating elevation.
- **Minimum Freeboard:** No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1:10 year (for Significant Consequence dams) when the pond is at its maximum reservoir water surface elevation during the passage of the IDF.

2 Estimation of Wave Run-up and Wind Set-up

Using procedures outlined in the Bureau of Reclamation Design Standards No 13: Embankment Dams (2012), wave run-up and wind set-up were estimated.

A frequency analysis of maximum daily wind speeds as recorded at Grande Prairie Airport station (ID 3072920 and 3072921) climate stations during for the period from 1955 to 2020 resulted in 10- and 1,000-year wind speeds of about 93 and 148 km/h, respectively, during West winds (see **Table V.1**).

Table V.1 Frequency Analysis for wind speeds (km/h) by direction of maximum gust

Wind Direction	Wind Angle (°)	Return Period (years)			
		10	100	200	1,000
N	0	68	91	99	115
NE	45	38	51	55	64
E	90	N/A	N/A	N/A	N/A
SE	135	24	26	27	28
S	180	20	28	31	36
SW	225	40	51	54	61
W	270	93	121	129	148
NW	315	86	114	122	141

The maximum wind speeds are expected to come from the West and Northwest. Therefore, the fetch length for the Bear River Reservoir was estimated to be about 405 m and 675 m, respectively, as shown in **Figure V.1**.

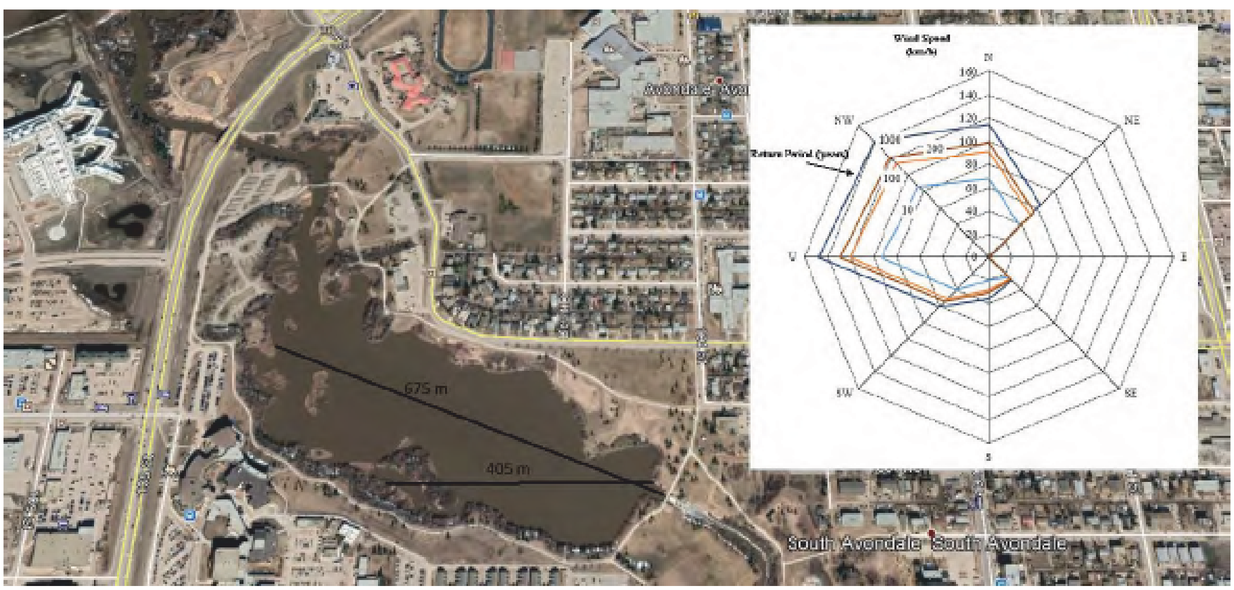

Figure V.1 Wind Rose and Fetch Length

The wind set-up, wave run-up, and total wind effects for the reservoir for West and Northwest wind are summarized in **Table V.2**.

Table V.2 Wind Set-up and Wave Run-up for Bear River Reservoir

	Wind Return Period (yr)	Wind Speed (km/h)	Wave Run-Up (m)	Wind Set-Up (m)	Total Wind Effects (m)
West Wind Fetch Length: 405 m	10	93	0.47	0.03	0.50
	100	121	0.58	0.03	0.61
	1,000	148	0.72	0.02	0.74
Northwest Wind Fetch Length: 675 m	10	86	0.59	0.04	0.63
	100	114	0.74	0.04	0.78
	1,000	122	0.79	0.04	0.83

3 Estimation of Freeboard

The minimum freeboard is required to minimize the risk of overtopping the embankment due to wind effects when the reservoir is at the peak water surface elevation during the IDF. According to the CDA guidelines, for dams with consequence classification “Significant”, the minimum required freeboard should be computed considering wind-generated waves resulting from the critical wind event with 1:10-year recurrence interval while the water surface is at maximum elevation during the routing of the IDF.

The normal specified freeboard protects the embankment during normal operating conditions against wind-generated waves resulting from the highest sustained velocity winds with 1:1000-year recurrence interval. The water surface elevation is considered to be at full supply level when these waves occur.

While the IDF can be routed through the spillway without causing an overtopping of the structure, the available (minimum) freeboard of 0.35 m is not sufficient to avoid wave overtopping under a 1:10-year wind. An additional 0.28 m additional freeboard is necessary to avoid overtopping by 95% of waves generated during this critical scenario, for a total of 0.63 m. The normal freeboard for the reservoir at FSL is adequate. Available freeboard estimated based on wave run-up elevations for normal and minimum conditions are summarized in **Table V.3**.

Table V.3 Summary of Estimated Run-up during Minimum and Normal Freeboard for Lowest Berm Elevation of 655 masl

Wind Direction	Freeboard Condition	Full-Supply -Level/ IDF Elevation (masl)	Wind Return Period (years)	Total Wind and Wave Effects/ Required Freeboard (m)	Available Clearance (m)	Available Freeboard (m)
West-Wind	Normal Freeboard	652.58[1]	1,000	0.74	1.68	2.42
	Minimum Freeboard (1:500-year flood)	654.65	10	0.50	-	0.35
Northwest-Wind	Normal Freeboard	652.58[1]	1,000	0.83	1.59	2.42
	Minimum Freeboard (1:500-year flood)	654.65	10	0.63	-	0.35

[1] Full-Supply-Level

4 References

U.S. Department of the Interior Bureau of Reclamation, 2012. Design Standards No. 13 Embankment Dams. Chapter 6: Freeboard.

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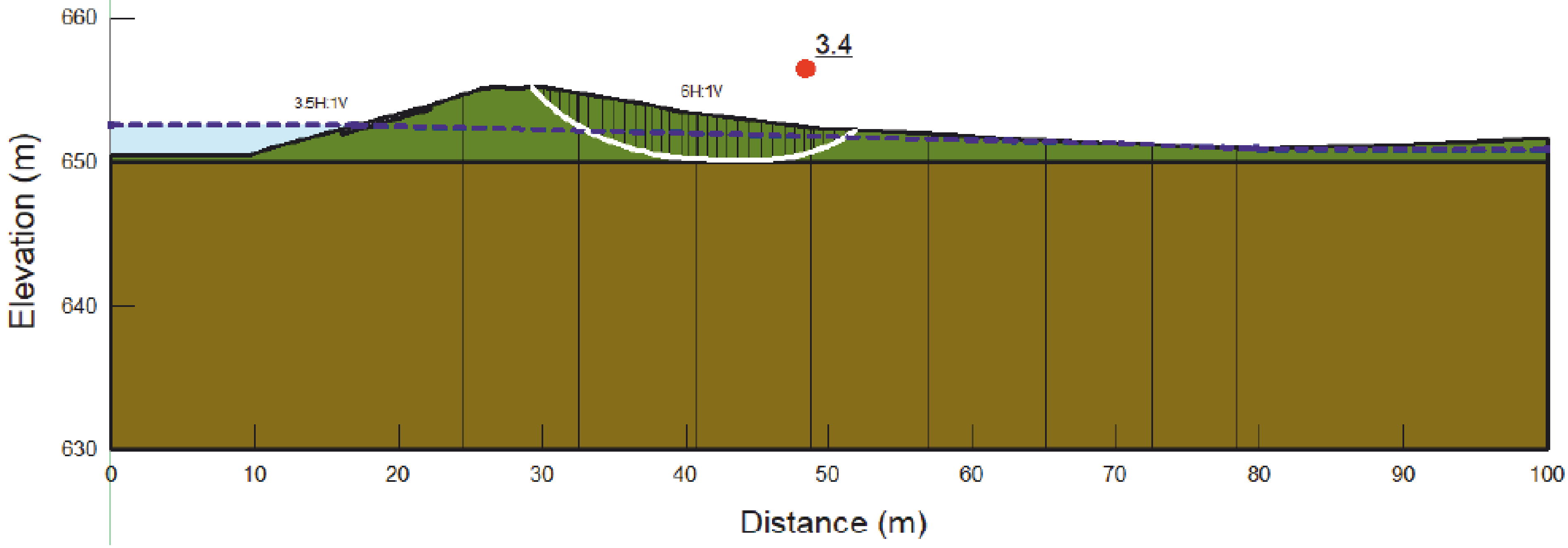
Appendix VI

Slope Stability Analyses Results

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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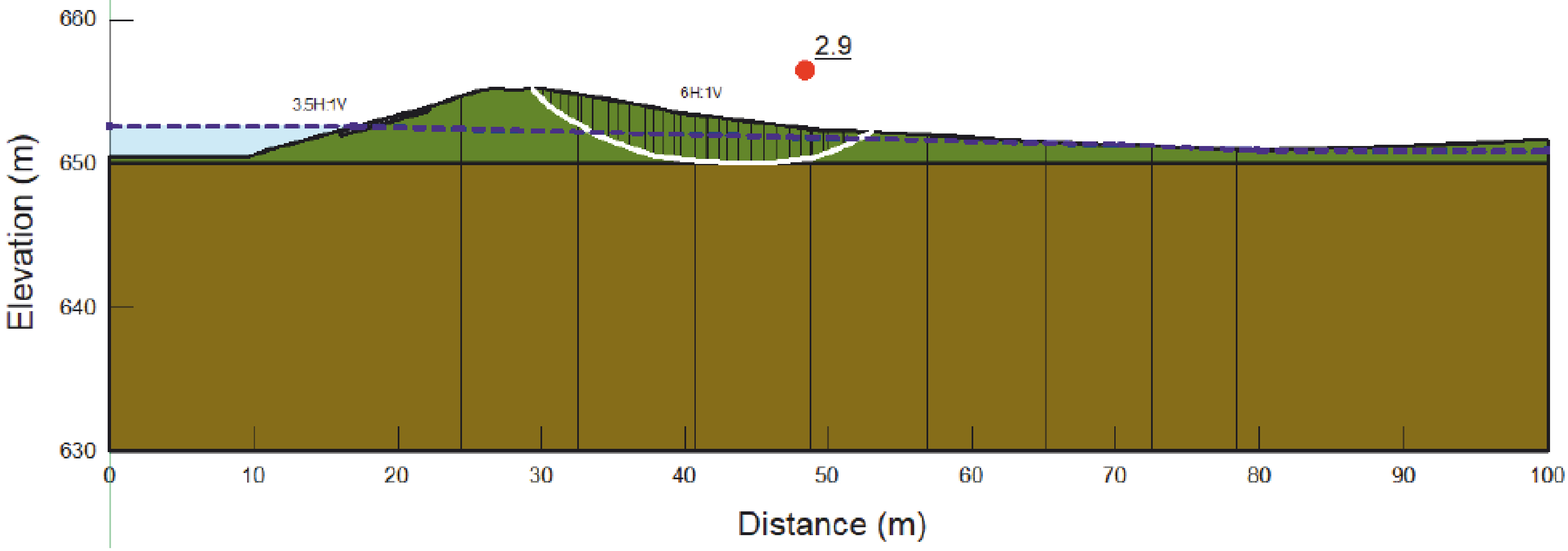
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** A-A'
Figure No.: VI-01	**Piezometric Surface:** Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Static

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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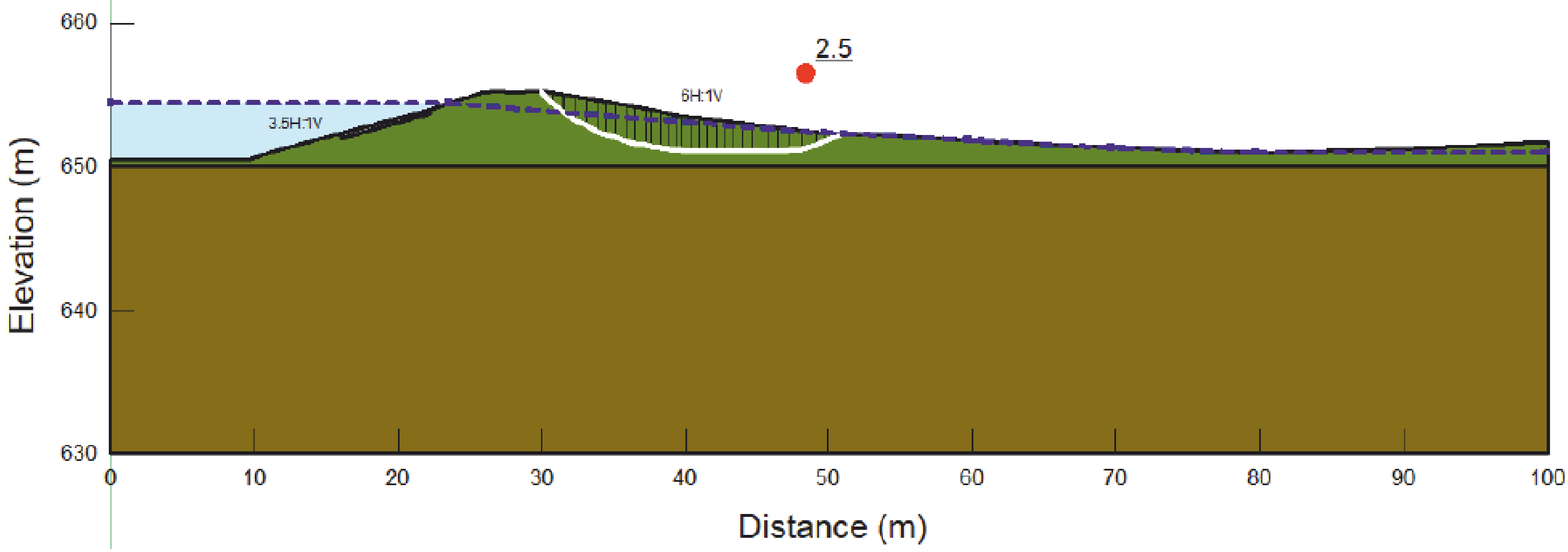
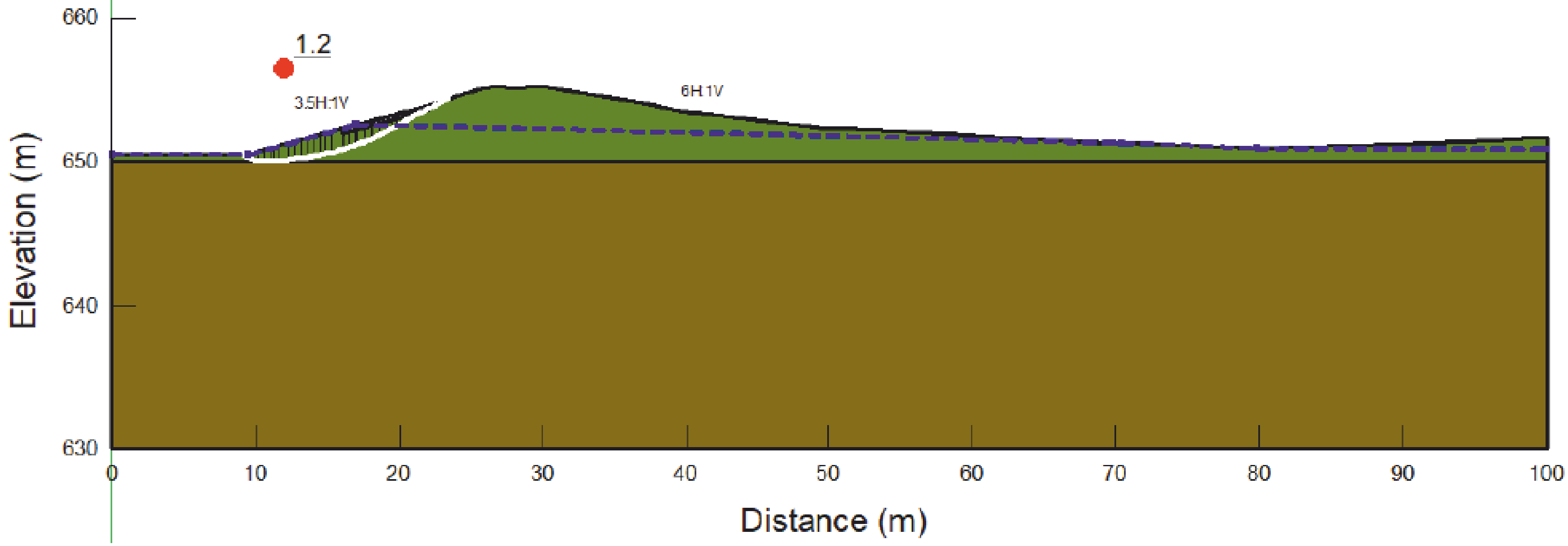
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** A-A'
Figure No.: VI-02	**Piezometric Surface:** Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Seismic

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
(brown)	Clay Til	Mohr-Coulomb	20	10	30	1
(green)	Embankment Fil	Mohr-Coulomb	19	0	28	1
(grey)	Riprap	Mohr-Coulomb	22	0	40	1



SNC·LAVALIN		
	Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
	Project No.: 676065	**Section:** A-A'
	Figure No.: VI-03	**Piezometric Surface:** Inflow Design Flood Level
	Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Static

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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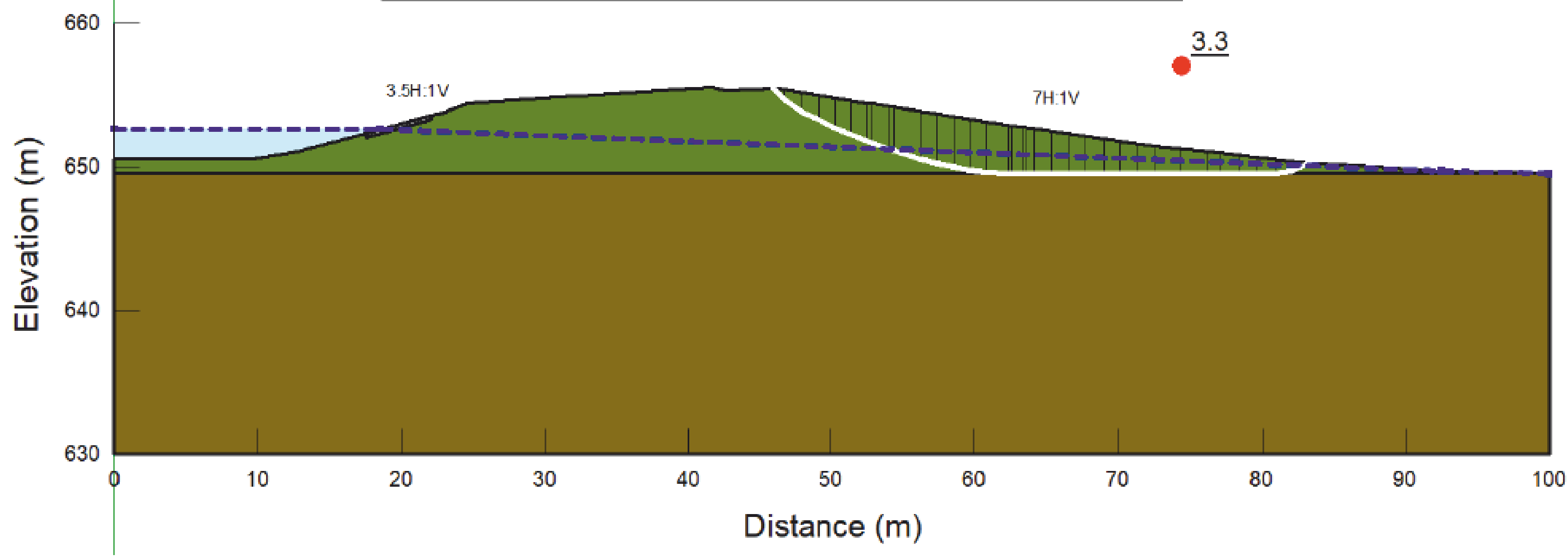
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** A-A'
Figure No.: VI-04	**Piezometric Surface:** Rapid Drawdown from Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Upstream Failure - Static

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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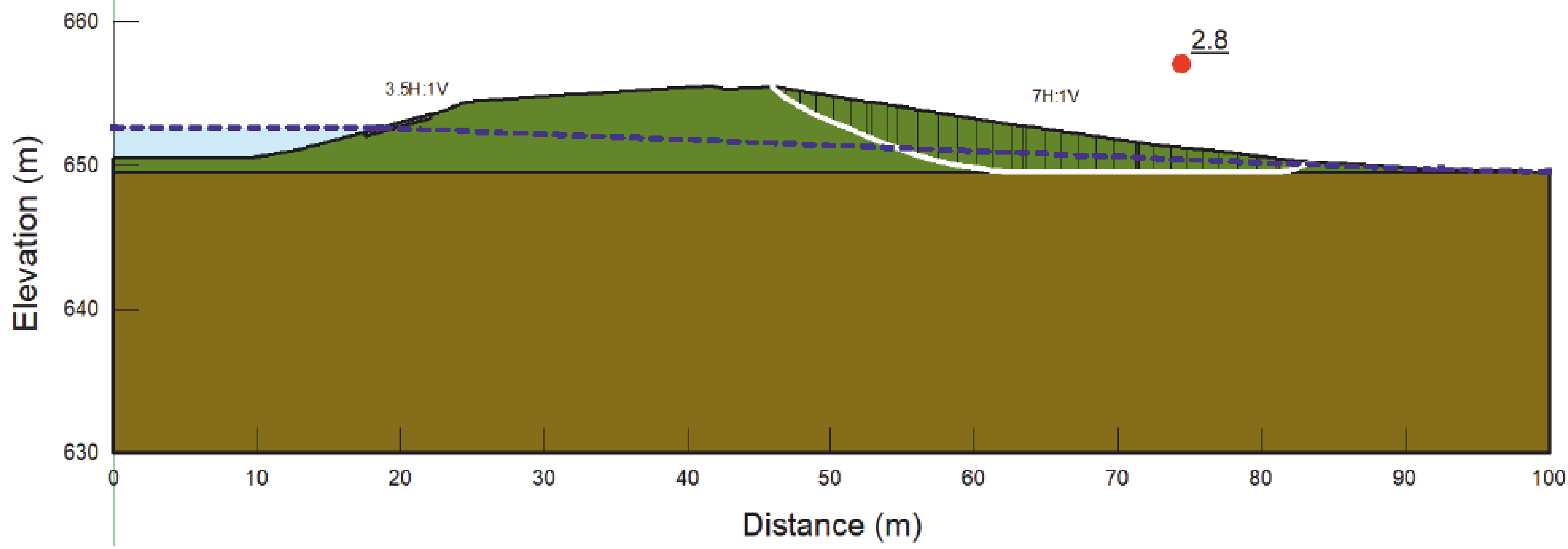
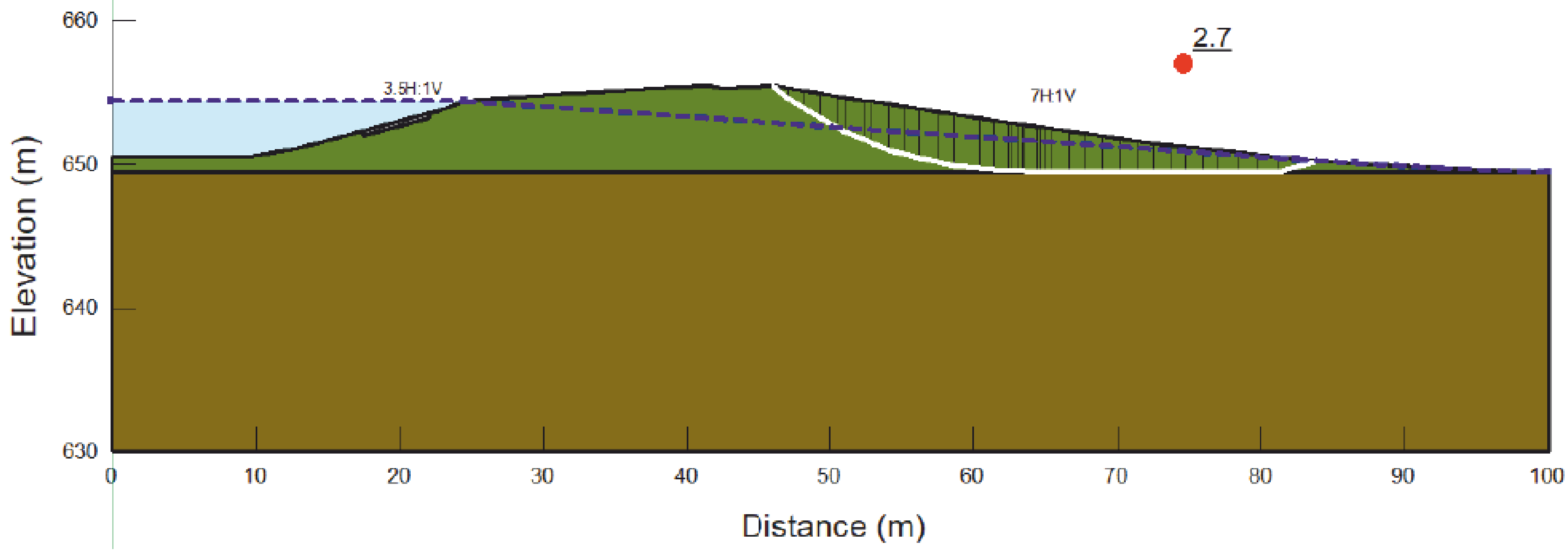
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** B-B'
Figure No.: VI-05	**Piezometric Surface:** Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Static

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



SNC·LAVALIN	**Client:** City of Grande Prairie	**Project Name:** Bear River Control Structure
	Project No.: 676065	**Section:** B-B'
	Figure No.: VI-06	**Piezometric Surface:** Full Service Level
	Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Seismic

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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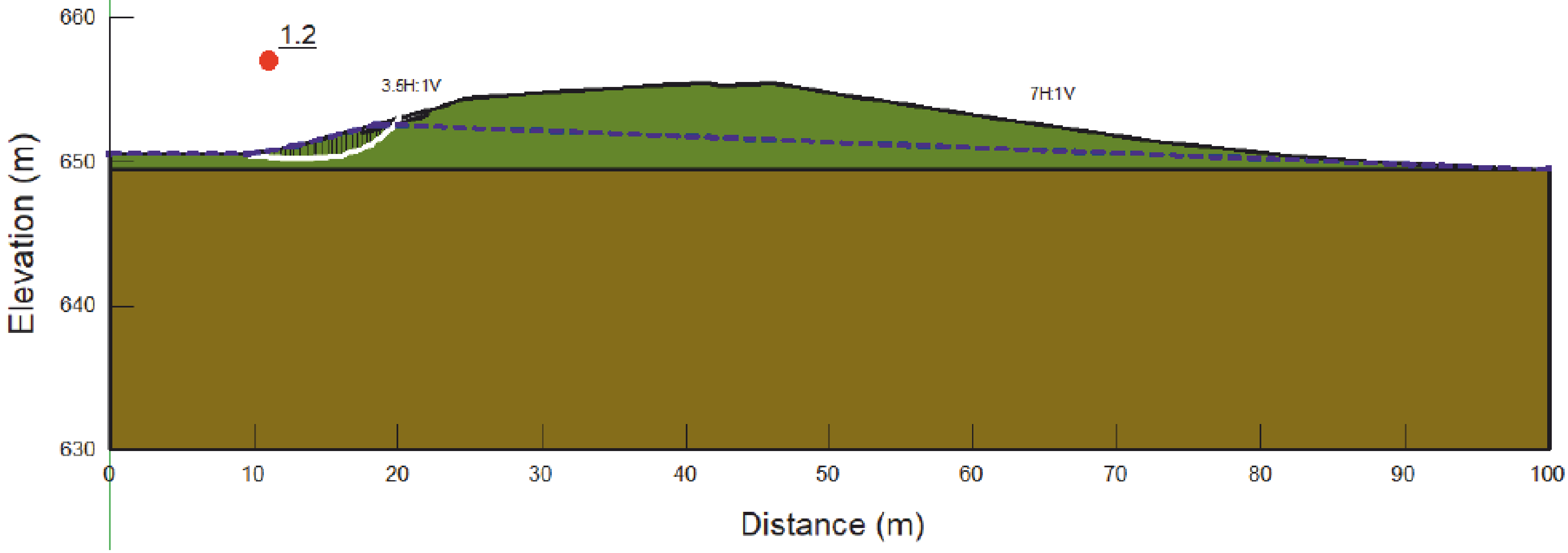
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** B-B'
Figure No.: VI-07	**Piezometric Surface:** Inflow Design Flood Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Static

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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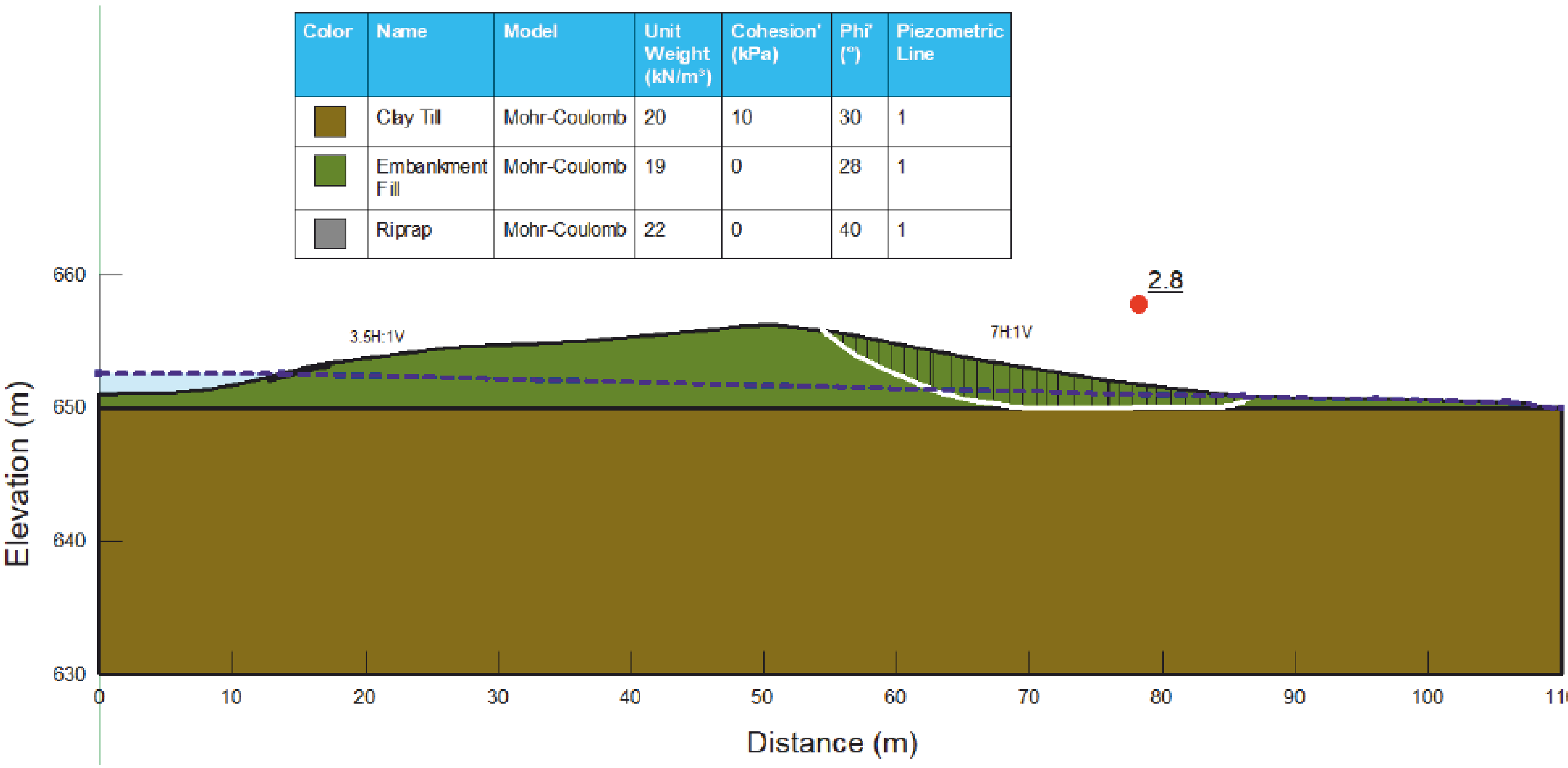
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** B-B'
Figure No.: VI-08	**Piezometric Surface:** Rapid Drawdown from Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Upstream Failure - Static



Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1

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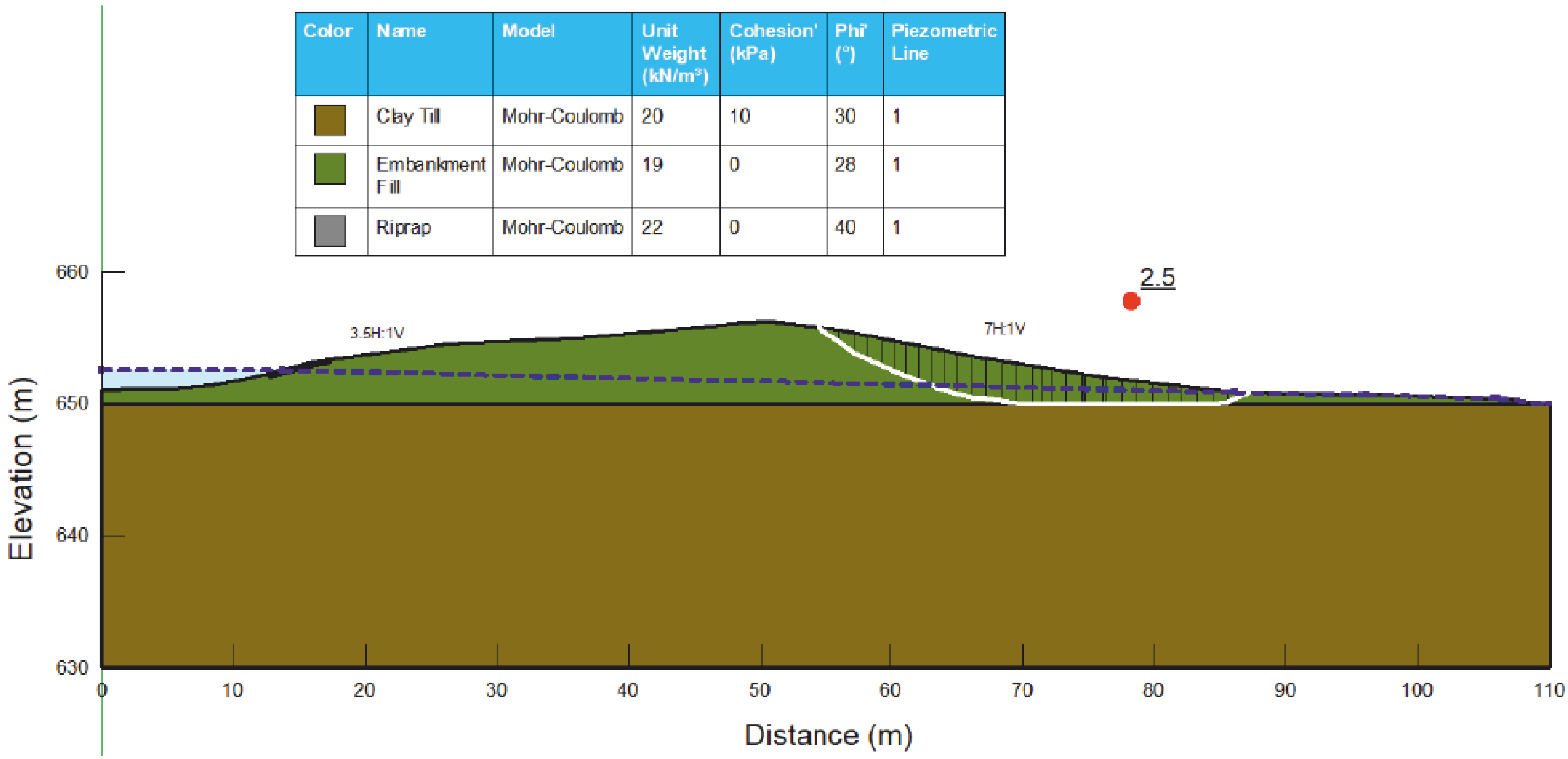
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** C-C'
Figure No.: VI-09	**Piezometric Surface:** Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Static



Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1

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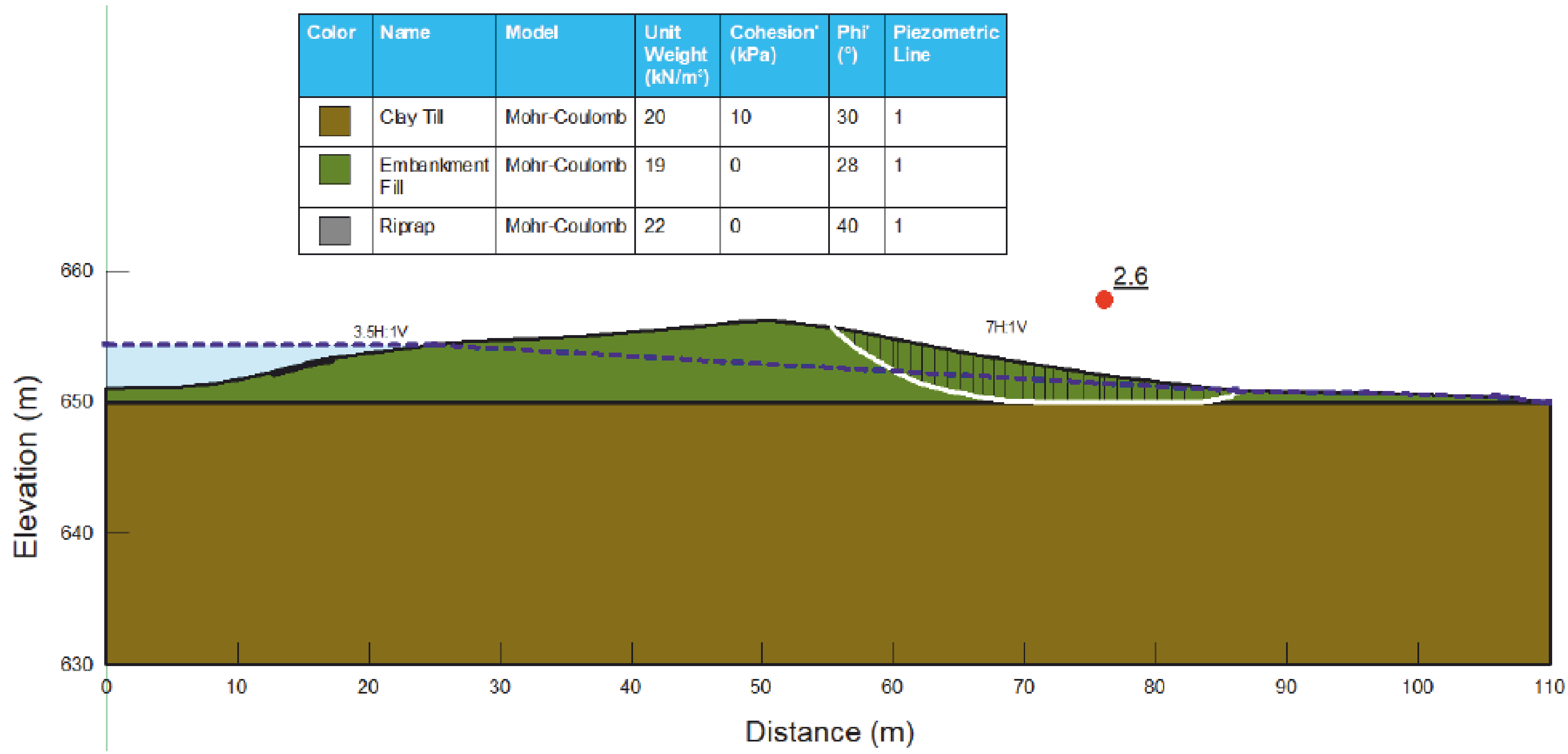
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** C-C'
Figure No.: VI-10	**Piezometric Surface:** Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Seismic



Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1

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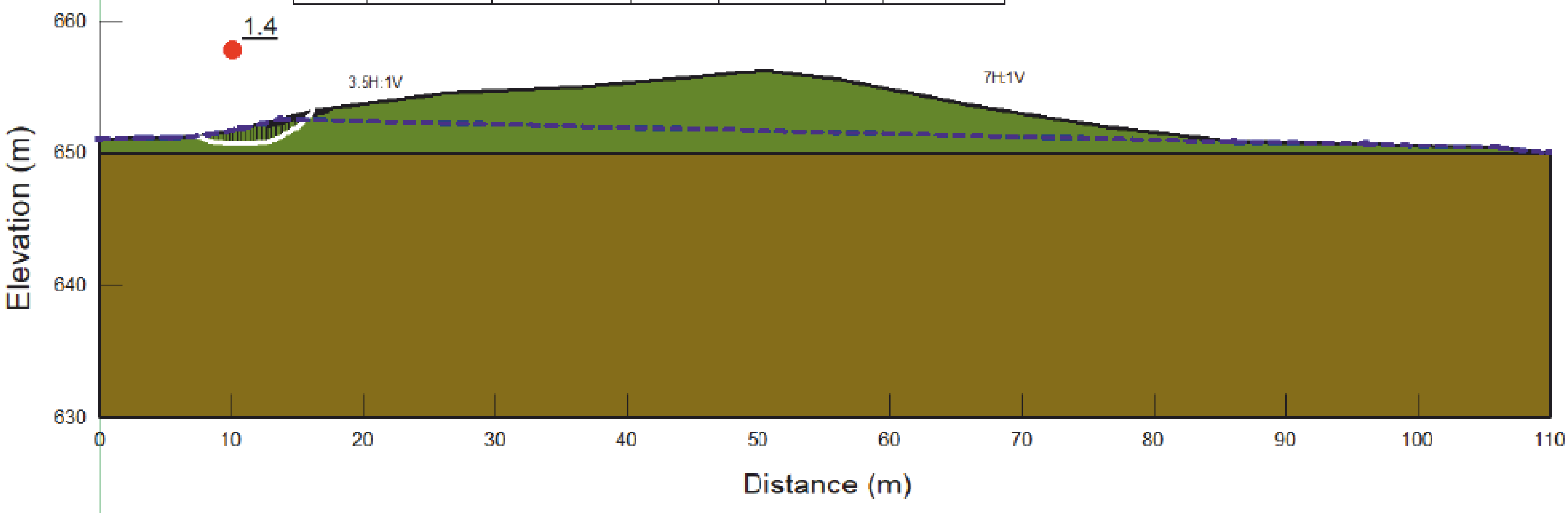
Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** C-C'
Figure No.: VI-11	**Piezometric Surface:** Inflow Design Flood Level
Date: 4-Dec-2020	**Case Displayed:** Downstream Failure - Static

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	Clay Till	Mohr-Coulomb	20	10	30	1
	Embankment Fill	Mohr-Coulomb	19	0	28	1
	Riprap	Mohr-Coulomb	22	0	40	1



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Client: City of Grande Prairie	**Project Name:** Bear River Control Structure
Project No.: 676065	**Section:** C-C'
Figure No.: VI-12	**Piezometric Surface:** Rapid Drawdown from Full Service Level
Date: 4-Dec-2020	**Case Displayed:** Upstream Failure - Static

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