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Subject: Ice Jam Monitoring and Response Plan – Highway 95 Bridges, Kicking Horse River, Golden

1 INTRODUCTION

The Highway 95 bridges cross the Kicking Horse River in the Town of Golden, British Columbia. Bridge 1 crosses over the main channel and Bridge 2 over Gould's Island side channel (see Figures 1 and 2). The bridges are the only vehicle crossing of the river and connect the north and south sides of the town. The shortest detour is an additional 100 km through Radium. A pedestrian bridge is located 300 m downstream of the Highway 95 bridges.

Several ice jams have impacted and loaded both bridges in the past, the bridges have been closed to traffic, but have not been significantly damaged. The highest ice jam occurred in December 2005 with the top of ice 0.7 m above the Bridge 1 low chord. Following an ice jam on December 23, 2022 (the fifth highest ice jam observed at the bridges), the British Columbia Ministry of Transportation and Infrastructure (MoTI) requested this ice jam monitoring and response plan (the plan) for the Highway 95 bridges.

The objective of the plan is to provide MoTI operations staff with a tool to semi-qualitatively assess the risk of an ice jam on the bridges, and determine if and what monitoring and response measures should be undertaken to protect the bridge and public safety. The plan provides a summary of ice jam processes and triggers, monitoring recommendations, and ice jam mitigation response recommendations. MoTI and Urban Systems Inc. (USL) provided input to Matrix Solutions Inc. on this plan during a workshop on March 20, 2023.

Recommended triggers to enact ice jam mitigation responses are focused on river ice conditions and ice levels present at the highway bridge. Ice jams are influenced by many climatic factors and conditions, primarily within the remote canyon reach upstream of the town, which is not accessible to vehicles or on foot. Although, predicting if an ice jam will occur and the magnitude/severity of ice jams will always carry uncertainties, this plan provides information and monitoring methods that can help forecast the risk of an ice jam occurring.

The Highway 95 bridges are planned to be replaced starting in late 2023 or early 2024; construction will last 2 to 3 years. The monitoring and response plan is general to the location of the bridges and not specifically for the existing or proposed bridges. It is recommended that MoTI require the contractor to supplement this plan with a construction specific ice jam response plan. The design ice elevation for the proposed highway bridge replacement is the ice jam of record. The proposed highway bridge will be 1.5 m higher than the existing bridge at the abutment and 3.0 m higher at the mid-span, thus clearing the ice

jam of record (0.8 m clearance at the abutment and 2.3 m clearance at mid-span). If requested by MoTI, this monitoring and response plan can be updated by Matrix after the bridge design is completed.

The river ice and ice jam terms used herein are defined at the end of this plan (under Section 4 Ice Definitions).

2 PLAN ORGANIZATION

Figure A (on the next page) provides a summary flow chart to determine the level of risk to the bridge due to ice jams and corresponding monitoring and response recommendations.

The remainder of the plan provides additional details and supporting information to the summary provided in Figure A organized as follows.

- Section 3: Basis – provides the basis of the ice jam monitoring and response plan including key inputs, data, and references.
- Section 4: Ice Definitions – provides definitions of the various river ice terminology used herein.
- Section 5: Ice Jam Processes and Triggers – summarizes the various factors and conditions that influence ice jam processes (i.e., ice generation, release, ice run and jamming, and timing of ice processes).
- Section 6: Monitoring Methods – lists and provides details of the available monitoring methods.
- Section 7: Possible Response Activities – lists the possible response activities to mitigate ice jams and key considerations.

The following figures are attached at the end of the plan.

- Table 1: Summary of Ice Jam Risk Factors
- Figure 1: Location Plan and Profile - Recommended Monitoring Locations
- Figure 2: Location Plan of Recent and Recommended Response Locations in Town
- Figure 3: Photographs of the Four Highest River Ice Levels Observed at the Bridges
- Figure 4: Typical River Ice Photographs and Historical Ice Jam Timing
- Figures 5 to 7: Temperature and WSC Data Winter of 2004/2005 2nd highest ice jam at the bridges, Winter of 2005/2006 Highest Ice Jam at Bridges (Ice Jam of Record), and 2006/2007 No Ice Jam Reported.
- Figure 8: Markup of Pedestrian Bridge Drawing, showing the pedestrian bridge has more clearance compared to the highway bridges.

1. ASSESS ICE JAM RISK TO BRIDGE

Factors to Assess
• Time of Year. • Conditions at Hwy 95 Bridge. • Air Temperature. • Conditions in Canyon Upstream of Town. • Conditions in Town and on Columbia River. • See attached report for details.

2. LEVEL OF CONCERN AND SUGGESTED TRIGGERS / KEY INDICATORS

3. RECOMMENDED MONITORING AND RESPONSE

Low Ice Jam Likelihood	Action	Frequency
• Early-November or late-January, and / or • An ice jam has not occurred, and the weather has been and is expected to be mild.	• None.	• N/A.

Medium Ice Jam Likelihood	Action	Frequency
• After November 15 and before January 15, and • Air temperatures are forecast to be less than -10°C for 5 or more consecutive days.	• Monitor river level on WSC website (station 08NA006). • Monitor weather and forecast.	• Weekly.

High Ice Jam Likelihood	Action	Frequency
• After November 15 and before January 15, and • Air temperatures have been less than -10 °C for 10 or more consecutive days or water level has sharply decreased.	• Monitor river level on WSC website (station 08NA006). • Monitor weather and forecast.	• Daily.
	• Vehicle reconnaissance of canyon.	• As soon as practical, then weekly.

Medium Risk to Bridge and High Ice Jam Likelihood	Action	Frequency
• Ice jam has recently occurred (within 4 weeks), • Little freeboard remaining at the bridge or remaining freeboard is rapidly decreasing (is or expected to be less than 0.5 m remaining freeboard in 1 day), and • May also consider: air temperatures have been or are forecast to be less than -10 °C for 5 or more consecutive days.	• Monitor river level on WSC website station 08NA006. • Monitor weather and forecast. • Vehicle reconnaissance of canyon.	• Daily.
	• Communicate with Town of Golden staff. • Engage an ice jam specialist to assess ice jam risk.	• As soon as practical, then weekly.
	• Consider a helicopter reconnaissance of the Town and canyon. • Consider putting equipment on standby for excavating ice jam.	• Pending initial review by ice jam specialist.

High Risk to Bridge	Action	Frequency
• Ice jam is or will soon be at or above the bridge low chord and may be loading the bridge. • May also consider: MoTI is concerned that a second ice run / ice jam could damage the bridge or cause unsafe conditions.	• Monitor river level on WSC website. • Monitor weather and forecast.	• Daily.
	• Communicate with Town of Golden staff. • Engage an ice jam specialist to assess ice jam risk. • Engage structural specialist to assess the bridge	• As soon as practical.
	• Helicopter reconnaissance of the Town and canyon. • Initiate response measures using best judgement and, if practical to do so, in consultation with ice jam and structural specialists (e.g., excavate ice jam).	• As soon as practical, then as recommended by ice jam specialist.

Possible Physical Responses and Key Considerations

1. Closing the Bridge to Traffic
   a) The bridge should be closed if there are concerns that the bridge could fail due to uplift or horizontal forces from the ice jam.
2. Weighing down the bridge
   a) Weighing down bridges has successfully prevented bridge failure for other bridges.
   b) A structural engineer should be consulted before weighing the bridge down.
3. Excavating river ice
   a) Excavation of the side channel has been successful in the past to provided flow relief around the bridge and reduced ice jam levels at the bridge. Excavation of the side channel is not likely to cause issues at the downstream pedestrian bridge (see Figure 8) but freeboard at the pedestrian bridge should be monitored before and during excavation.
   b) Excavation within the main channel at the bridge has been successful in the past to reduce peak ice jam levels temporarily / locally and relive stress on the bridge.
   c) Excavating the toe of the ice jam or grounded ice can release some of the ice jam, and / or reduce the blockage of flow, and thus decrease ice levels at the bridge. The toe of jam may be visible as a drop in river ice levels along the river (no photograph examples are available to Matrix). However, when the toe of jam or when the ice is grounded within the gravel bars it is typically not visible. The most likely location for the toe of jam or grounded ice is within the gravel bars. Excavating within the thalweg (the deepest part of the river) is expected to be the most effective to relive blockage of the flow. Excavation of the ice jam within the gravel bars has successfully relieved flow and reduced ice jam levels at the bridge in the past.
   d) Excavation may not be effective where / when there is a high content of frazil ice due to the slushy consistency.
   e) A long reach excavator is recommended. A standard reach excavator may not be as effective.
   f) The effects on the ice jam upstream and downstream should be carefully monitored during excavation. Although not likely to be a concern due to the high content of frazil ice, excavation could shift ice and increase the blockage of flow. If there are any concerns before or during excavation, the Town of Golden and an ice jam specialist should be consulted.

Other Notes:

1. Triggers for monitoring and response are suggested values. Risk to the bridge should be considered on a case-by-case basis. Additional considerations and factors may indicate higher risk levels and warrant response measures before indicated on this flow chart. For example, if a large accumulation of ice and / or rock avalanche has created a significant volume of pooled water in the canyon, that could release.
2. Refer to Figure 1 and 2 for recommended monitoring and response locations.
3. Refer to the attached report for further details on ice jam processes and factors that affect ice jams.
4. Ice jams can shift at unexpected times, and the ice and water create hazards which are especially significant to workers on foot. Any work near or on the river during an ice jam should be carefully planned to ensure the safety of workers.
5. Online links to monitoring resources provided below (Refer to the attached report for further details on monitoring measures).
   a) WSC real time data on Kicking Horse River: https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08NA006
   b) Environment Canada Forecast in Golden: https://weather.gc.ca/city/pages/bc-34_metric_e.html
   c) Environment Canada Historical Records in Golden: https://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=54318

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Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

British Columbia Ministry of Transportation and Infrastructure
Highway 95 Bridges - Kicking Horse River – Ice Monitoring and Response Plan

Ice Jam Monitoring and Response Plan

Date:	Project:	Submitter:	Reviewer:
April 2023	5635-522	Z. Berti	D. Kushner

Figure A

3 BASIS

The basis for this plan includes the following.

1. Discharge (58-year record), water level, and ice data (freeze-up and break-up dates) from Water Survey of Canada (WSC) for the hydrometric station on the Kicking Horse River at Golden (Station 08NA006).

2. Data and conclusions on Kicking Horse River ice jams from the 2018 Ice Jam Study that was completed by Matrix for the Town of Golden (Matrix 2018). The study included a summary of historical and recent ice jam records from 1897 to 2018 including photographs of ice jam levels at the existing bridges.

3. Photographs and documentation of MoTI observations of an ice jam that occurred during the 2021/2022 winter. The ice jam occurred on December 31, 2021, and ice levels peaked at the Highway 95 Bridge on January 3, 2022. The peak ice level was approximately at the existing low chord of Bridge 1. An ice jam in December 2014 also peaked at the low chord of Bridge 1, thus the December 2014 and 2021 ice jams were the third and fourth highest ice jams at the bridge.

4. Photographs and documentation of MoTI observations of an ice jam that occurred during the 2022/2023 winter. The ice jam occurred in late December 2022, and ice levels peaked at the Highway 95 Bridge on December 23. The average peak ice level across the channel was about 0.2 m below the low chord of Bridge 1, although some individual ice floes were higher. This was the fifth highest ice jam observed at the bridges.

5. As-built drawings of the existing bridges were provided by the MoTI. Construction of the bridges was completed in 1951.

6. Annual inspection reports of the bridges were provided to Matrix by the MoTI for 2015 to 2020.

7. Numerous site visits and site photographs taken by Matrix (formerly Hydroconsult) for the period of 1999 to 2022, including observations of the river substrate. Matrix has been involved in river engineering along the Kicking Horse River for more than 20 years including river surveys, hydraulic modelling, river ice engineering, sedimentation studies, hydrotechnical design, construction supervision, and inspection of the pedestrian bridge and dikes for the Town of Golden.

4 ICE DEFINITIONS

Anchor Ice: Ice that forms when frazil ice adheres (or anchors) to the river bed. If enough anchor ice accumulates, an ice dam can form, which increases water levels upstream. Anchor ice and anchor ice dams can release from the bed in response to solar heating or flow fluctuations.

Border Ice: Typically the first ice that forms on the river; it forms in the slow moving and calm areas near the banks or around gravel bars. The border ice (also called shore ice) will thicken and extend out from the banks or gravel bars over time.

Brash Ice: Accumulation of floating ice made up of fragments; the wreckage of other forms of ice.

Equilibrium Ice Jam Thickness: The maximum thickness of an ice jam that is reached when a sufficient quantity of ice has accumulated so that the downstream forces on the ice cover (weight of ice and drag on underside of ice) are resisted by the combined internal strength and bank shear.

Frazil Ice: Ice that forms in turbulent fast moving water that is slightly below freezing; it looks similar to ice shavings, has a slushy consistency, and tends to group together. Frazil ice formation occurs on nucleation sites (also called seed particles) usually consisting of impurities in the water such as tiny particles of dust, sediment, organic material, snow particles, frozen droplets from splashing, etc. Formation can also occur in pure water when water temperatures are -30 to -40^{o}C (which is understandably rare).

Grounded Ice Jam: These are ice jams that extend right to the river bed, leaving only the voids between the ice floes as paths for water to pass. This is much less hydraulically efficient than flow underneath the ice accumulation, causing water to back up more severely upstream. Grounding can occur by a variety of mechanisms, for example: the sudden halt of an ice run, the collapse of a floating ice jam once the wave passes downstream, when entrained ice floes get caught up under the ice cover blocking the passage of other ice floes, or when progressive shoving and thickening occur in large or steep rivers.

Head of Jam: Refers to the upstream end of an ice jam. The head of an ice jam will progress upstream if incoming ice floes accumulate at the head through juxtaposition.

Ice Floe: A floating free mass of ice.

Ice Jam: A stationary accumulation of fragmented ice or frazil ice that restricts flow on a stream.

Ice Run: Refers to a relatively large number and closely spaced ice floes that are moving (flowing) with the water. Also refers to the initial accumulation of ice that forms an ice jam.

Ice Shear Wall: The steep face of ice that is left along the river banks after a portion of the ice cover or jam has broken and transported downstream.

Toe of Jam: Refers to the downstream end of an ice jam, where ice floes began to accumulate to form the jam. The toe of the jam generally forms where there is some barrier to the ice floes such as constrictions in the channel, gravel bars, instream structures, intact ice cover, or other barriers.

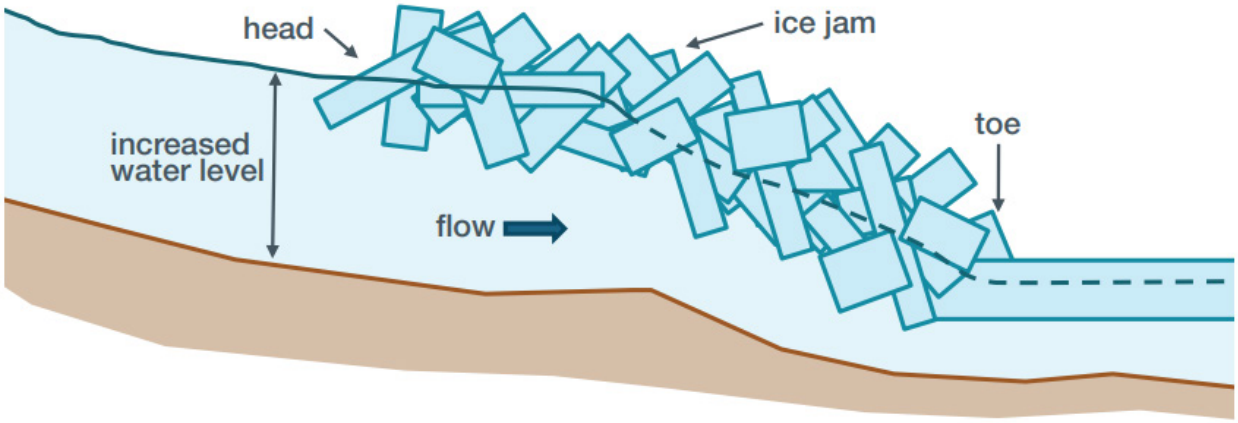

Figure B: Side View of an Ice Jam (GoA 2018)

5 ICE JAM PROCESSES AND TRIGGERS

The following description represents Matrix's current understanding and hypothesis of ice processes, timing, and triggers on the Kicking Horse River. Some of the information herein may be subject to revision in the future when more data and observations become available (e.g., observations at the bridges from MoTI and data from the Town of Golden Ice Monitoring System).

Locations along the river are referenced as stations as shown on Figures 1 and 2 (e.g., the highway bridges are located at Sta. 2+000). Example photographs of ice jams and other typical ice conditions are provided on Figures 3 and 4.

5.1 Ice Generation

The primary contributor to ice jams in Golden is ice generation in the 25 km long canyon upstream of town (about 3+300 to 28+000, Figure 1). This steep canyon generates extensive frazil and anchor ice that, when released, deposits in the lower gradient reach through town (about 3+300 to 0+000). Above the canyon, the river transitions to a flatter gradient and the ice forms a stable ice cover that likely does not release and therefore does not contribute to ice jam problems in Golden.

Ice generation within the river in the canyon consists of:

- **Border ice** – forms in low velocity areas such as adjacent to the banks, gravel bars, pools, bridge piers, or sharp bends. Border ice has a high density, high internal strength, and grows outwards into the river and thickens.

- **Frazil ice** – frazil ice forms best in supercooled (less than 0°C), turbulent, open water. These conditions are abundant in the canyon upstream of town from early to mid-winter. During late-winter, frazil ice generation decreases because of increasing ice cover, which decreases the amount of open turbulent water. Frazil ice has a low density, low internal strength, slush like consistency, and is easily transported downstream by the river flow.

- **Anchor ice** – frazil ice can adhere to the riverbed to form large masses of ice on the riverbed called anchor ice. This submerged anchor ice can continue to grow, forming small ice dams, which pool water upstream and act as barriers to ice floes. Anchor ice has a high to medium density, and medium to high internal strength.

5.2 Ice Release

There are several possible mechanisms that could trigger the release of ice from the canyon that is subsequently transported into the town (i.e., an ice run):

- When the destabilizing forces (buoyancy and water pressure from upstream pooled water or increased flow) exceed the resisting strength of the ice mass (adhesion to the bed and banks or internal strength). The adhesion of ice to the bed is a function of air and water temperature. Warming weather, increased solar radiation, or increased river flow may release the anchor ice formations within the canyon.

- The resulting dynamic surge of water and ice from an individual ice mass release may dislodge downstream ice formations. Avalanches, rockfalls, or other blockages of the river flow result in accumulation of ice floes that can also release and dislodge downstream ice formations. These ice releases can form a wave of ice and water that grows as it progresses downstream. The ice runs may stall within tight bends, such as those upstream of the town near CPR Railway Bridges 2 and 3 (4+000 to 6+000).

- Once an ice release clears the canyon of ice obstructions, continued cold weather can result in large volumes of frazil generation, which are now free to flow into the town.

Frazil ice runs may also occur during early-winter while most of the canyon still has open water conditions.

Multiple ice jams can occur over a single winter resulting from the release of the ice build-up above the town followed by additional releases or the continued generation of frazil ice due to the exposed water surface.

5.3 Ice Run and Lodgement (Jamming)

Once an ice run reaches the town, its momentum is slowed by the flatter river gradient (from 0.6% at the mouth of the canyon to 0.1% near the Columbia River, which slows the velocity of ice and water), and other barriers to the ice floes. These barriers include constrictions of the river due to the dikes, islands, gravel bars, the CPR Bridge Piers at 0+200, and ice cover on the Columbia or lower Kicking Horse rivers. It is uncertain how much each of these barriers contribute to ice jams. Observed jam toes since 2004 have typically been at the gravel bars near the CPR Bridge.

Because ice floats with 92% of its thickness submerged, the ice cover obstructs part of the effective flow area. This reduces flow velocity and so, for the same discharge, the flow depth will be greater in an ice-covered channel than it will be under open-water conditions. Incoming frazil ice may become trapped on the underside of the ice cover, resulting in thickening of the ice jam, while some frazil may continue to pass under and past the ice jam.

Frazil ice trapped under the jam may accumulate and entirely block the channel, with water flow only able to seep through the small voids (pores) in the frazil ice. This results in increasing ice and water levels until and equilibrium is reached or some of the blockage is cleared by the increasing water pressure.

After a jam has occurred, the underside of the ice cover generally smoothens as time progresses. This is caused by several factors including: continuous erosion on the underside of the ice by the flowing water, freeze-thaw cycles that result in consolidation of the ice mass, and minor melting caused by sun and/or water temperatures above freezing. Eventually temperatures will warm enough, and an open lead will often form at the toe of the jam. Continued warm temperatures will lead to break-up of the ice allowing the flow to transport it downstream. Friction from flowing water can also gradually erode ice covers and ice jams. The ice cover may also cave in if water levels under the ice recede and leave the ice unsupported.

5.4 Timing of Ice Processes

Recorded freeze-up, ice jam, and break-up dates are shown on Figure 4 and summarized below.

- Freeze-up typically occurs from early-November to early-December.

- Ice jams in town typically occur from mid-November to early-January. When ice jams occur, they typically remain until break-up. The earliest ice jam occurred on November 22 in 1956. The latest ice Jam occurred on January 16 in 1973.

- Break-up typically occurs from late-February to mid-April. Ice jams are not a concern during break-up on the Kicking Horse River.

5.5 Summary of Factors Indicating Jam Risk and Severity

A summary of the key factors that influence the likelihood of ice jams occurring and ice jam severity are described below. A summary is provided in Table 1 (attached).

- Time of year – ice jams typically occur from mid-November to early-January. The earliest ice jam occurred on November 22, and the latest on January 16. The risk of ice jams occurring before November or after January is very low.

- Air temperature.

    - Ice generation – ice generation is driven by cold air temperatures. Lower temperatures for more consecutive days increase the risk of ice jams occurring. A rule of thumb used by the Town of Golden staff is that the likelihood of an ice jam occurring is increased when there are at least 7 consecutive days with maximum daily temperatures are less than -10 °C.

- Ice release from the canyon – ice jams may be initiated (triggered) when warming temperatures and/or solar radiation on sunny days result in the release of river ice from the canyon upstream of the town (see Figures 5 and 6). The exact temperature and conditions when ice is released from the canyon is complex and uncertain, and released ice may also become jammed within the canyon before reaching the town.

- River water temperature – when the river water temperature is below 0 °C, the water is supercooled, and the risk of frazil generation is increased.

- River flow (water level) – sharply decreasing flow and water level in the town (e.g., over several hours to a day) could indicate that significant volumes of ice are being generated in the canyon, or that there is a blockage of flow in the canyon, and that an ice jam/ice run may be imminent (example shown on Figure 5). Ice jams have not always occurred in these cases; decreasing water level is also a normal response to colder temperatures, gradual ice generation, and/or reduced precipitation in the winter that decrease the runoff and flow into the river.

- Other Conditions in canyon.

  - Avalanches or other blockages – avalanches, rockfalls, or other blockages of the river flow result in accumulation of ice floes. When the blockage or accumulation of ice floes releases, it may dislodge downstream ice formations, that can form a wave of ice and water that grows as it progresses downstream.

  - Ice volume and ice cover – the amount/volume of ice in the canyon is an indicator of the potential likelihood and severity of ice jams:

    - Increasing ice volume indicates increasing potential ice jam level (increased severity) – The volume of ice in the canyon is the potential amount of ice that could be released and jam in the town. The volume of ice in the ice jam generally increases the level of the ice jam (until an equilibrium is reached where the ice jam continues to accumulate and build in the upstream direction without increasing the downstream ice jam levels). Thus, a high volume of ice present in the canyon represents a high potential ice jam volume, and high potential ice jam level.

    - Conversely, increasing ice cover decreases the likelihood of an ice jam occurring – As the volume of ice in the canyon increases, the resistance of the ice being released generally increases as well. As the ice grows and covers and fills the canyon, it forms a larger, continuous masses that become stronger and have more contact against the riverbed and canyon.

    - The amount of open water (if also occurring with low air temperatures and supercooled water) increases the generation of frazil ice and thus increases the likelihood and potential ice jam severity.

- Other Conditions in town and on Columbia River.

  - Previous ice jam or other blockage – increase the likelihood than incoming ice floes will jam in the town or at the bridges, rather than continue to be conveyed further downstream. For example, if a solid ice cover or previous ice jam is present on the Kicking Horse or Columbia rivers.

6 MONITORING

Possible monitoring activities include the following:

- River water level at WSC gauge – real time water level from the WSC gauge (located 0.7 km downstream of the bridges, see Figure 2) can be monitored from the following online website. Note that the discharge (flow) reported by the gauge is not accurate when river ice is present.
    - WSC Real time data: https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08NA006
- Weather & forecast – air temperature can be monitored from the Environment Canada weather forecast (link below) or any other forecasting agency. Recorded past weather data can be accessed from the Environment Canada archives.
    - EC forecast: https://weather.gc.ca/city/pages/bc-34_metric_e.html
    - EC records: https://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=54318
- Town monitoring system – photographs, river level sensors, and water temperature (see locations on Figure 1 and 2) are available on the Town of Goldens Ice Monitoring System. The town may be willing to provide access to the monitoring system or provide a summary of the data to the MoTI.
- Ground reconnaissance of the river – river conditions in the town and along the canyon reach can be visually monitored by vehicle and/or on foot. Along the canyon, the river can be viewed from the Park (10 Mile) and Yoho (5 Mile) bridges, and at the Highway 1 rest stop (see Figure 1).
- Helicopter reconnaissance of the river – visibility of the canyon reach is limited to the several locations mentioned above. Whereas a helicopter reconnaissance allows for an assessment of the entire canyon and the town and Columbia River with a 1 or 2 hour flight. It is recommended that the helicopter reconnaissance include Town of Golden staff, who are familiar with monitoring ice jams, or other ice jam specialists.

7 POSSIBLE RESPONSE ACTIVITIES

Possible monitoring activities and key considerations are summarized below.

If time with respect to current risk to the bridge permits:

- Engage an ice jam specialist to assess ice jam risk.
- Inspect bridge and/or engage structural specialist to assess risk to the bridge(s).
- Close the bridge to traffic – the bridge should be closed if there are concerns that the bridge could fail due to uplift or horizontal forces from the ice jam.
- Weigh the bridge down to resist any uplift forces from the ice jams (e.g., with loaded trucks).
    - Weighing down bridges has successfully prevented bridge failure for other bridges.

- A structural engineer should be consulted before weighing the bridge down.

If urgent response is required due to imminent risk to the bridge:

- Excavate river ice to relive water flow/flow of ice - recommended excavation locations are shown on Figure 2.
    - Excavation of the side channel has been successful in the past to provided flow relief around the bridge and reduced ice jam levels at the bridge. Excavation of the side channel is not likely to cause issues at the downstream pedestrian bridge (see Figure 8, which shows that the pedestrian bridge provides 2.0 m more clearance at the mid-span compared to the highway bridge), but freeboard at the pedestrian bridge should be monitored before and during excavation.
    - Excavation within the main channel at the bridge has been successful in the past to reduce peak ice jam levels temporarily/locally and relive stress on the bridge.
    - Excavating the toe of the ice jam or grounded ice can release some of the ice jam, and/or reduce the blockage of flow, and thus decrease ice levels at the bridge. The toe of jam may be visible as a drop in river ice levels along the river (no photograph examples are available to Matrix). However, when the toe of jam or when the ice is grounded within the gravel bars it is typically not visible. For example, frazil ice jams can be very similar in appearance to snow cover on the river/river ice downstream of the toe of the jam. The most likely location for the toe of jam or grounded ice is within the gravel bars. Excavating within the thalweg (the deepest part of the river) is expected to be the most effective to relive blockage of the flow. Excavation of the ice jam within the gravel bars has successfully relieved flow and reduced ice jam levels at the bridge in the past.
    - Excavation may not be effective where there is a high content of frazil ice due to the slushy consistency.
    - A long reach excavator is recommended. A standard reach excavator may not be as effective.
    - The effects on the ice jam upstream and downstream should be carefully monitored during excavation. Although not likely to be a concern due to the high content of frazil ice, excavation could shift ice and increase the blockage of flow. If there are any concerns before or during excavation, the Town of Golden and an ice jam specialist should be consulted.

Ice jams can shift at unexpected times, and the ice and water create hazards, which are especially significant to workers on foot. Any work near or on the river during an ice jam should be carefully planned to ensure the safety of workers.

8 CLOSURE

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 403.237.0606.

Yours truly,

MATRIX SOLUTIONS INC.

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Reviewed by

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DK/jp

Permit to Practice No. 1001734

CONTRIBUTORS

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VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V0.1	15-Mar-2023	Draft	5635-522 Ice Plan 2023-03-09 draft V0.1	Issued to client for review
V0.2	4-Apr-2023	Draft Revised 1	5635-522 Ice Plan 2023-04-04 draft V0.2	Updated with MoTI and USL input from March 20, 2023 meeting. Issued to client for review.
V0.3	24-Apr-2023	Draft Revised 2	5635-522 Ice Plan LR 2023-04-24 draft V0.3	Updated with comments from MoTI. Issued as draft.
V1.0	3-May-2023	Final	5635-522 Ice Plan LR 2023-05-03 final V1.0	Issued as final

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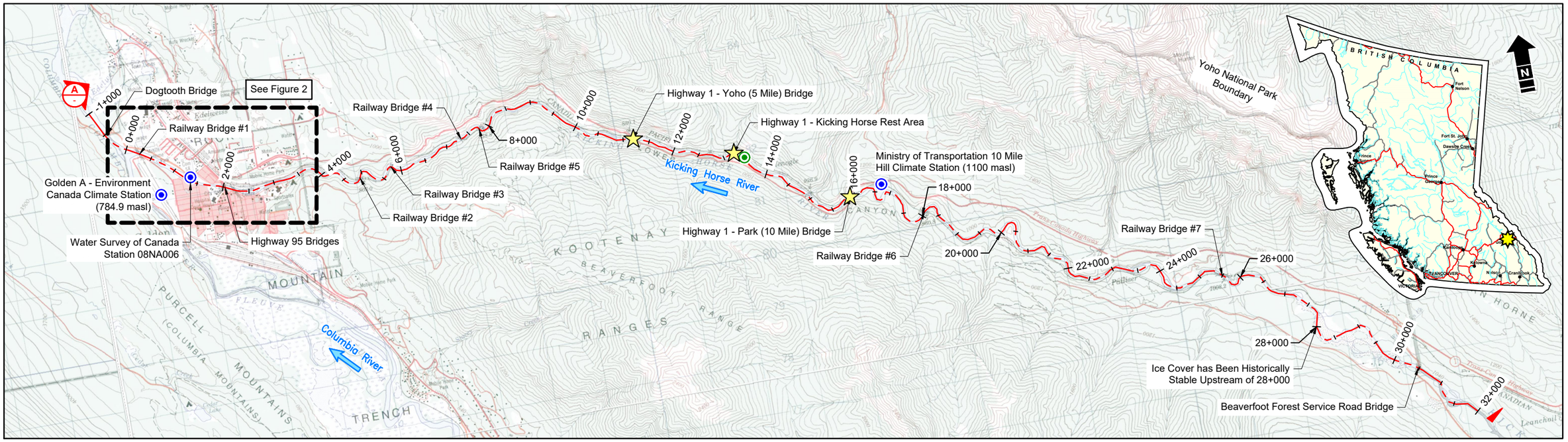
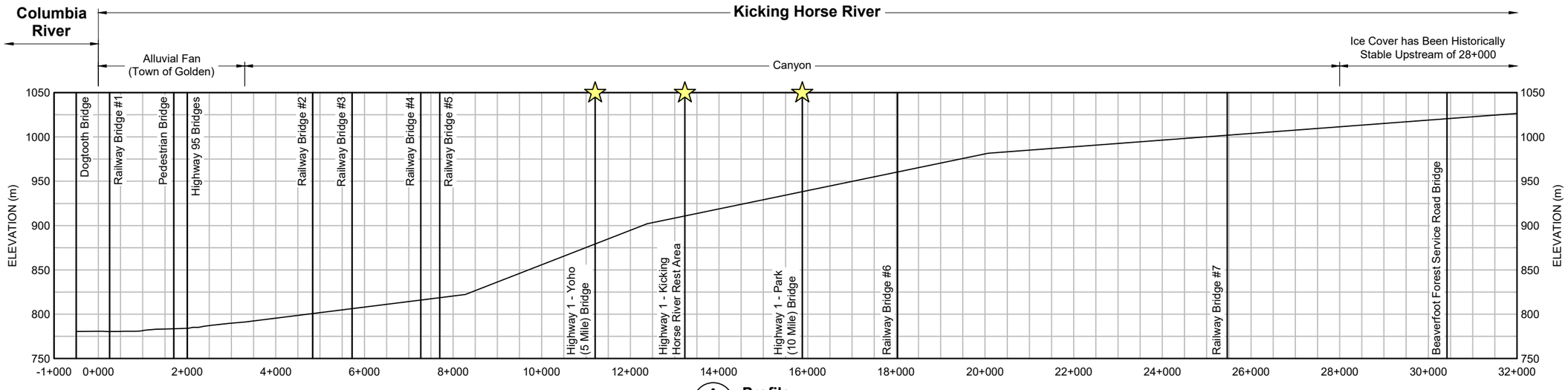
Government of Alberta (GoA). 2018. *Ice Jam Flooding*. December 2018. https://open.alberta.ca/dataset/bc810165-232e-4408-aa92-36759b5207a3/resource/f94a9ce2-84e6-4635-a835-5d1d237ba8c2/download/aep-rfc-factsheet-ice-jam-flooding.pdf

Matrix Solutions Inc. (Matrix). 2018. *Kicking Horse River Ice Jam Study, Town of Golden, British Columbia*. Version 1.0. Prepared for The Town of Golden. Calgary, Alberta. April 2018.



Plan View



A / **-** **Profile**
Horizontal Scale 1:100,000
Vertical Scale 1:5,000

1 : 75,000 metres
750 0 750 1500
UTM83-11

Reference: 82N 01 (Mount Goodsir), 82N02 (McMurdo), 82N06 (Blaeberry), 82N07 (Golden). Edition 4, UTM Zone 11, NAD 83, Department of Natural Resources Canada. All rights reserved.
Cross-section surveys (including top of bank / dike) most recently completed by WSP Global Inc. in October 2017.

BRITISH COLUMBIA Ministry of Transportation and Infrastructure

Matrix Solutions Inc. ENVIRONMENT & ENGINEERING

LEGEND

- Recommended MoTI Ground Monitoring Location
- Town of Golden Ice Monitoring Station
- Climate / WSC Station
- 2+000 — Kicking Horse River Chainage, measured from 0+000 at Confluence with Columbia River and Based on Current River Alignment

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

British Columbia Ministry of Transportation and Infrastructure
Highway 95 Bridges - Kicking Horse River - Ice Monitoring and Response Plan

Location Plan and Profile Recommended Monitoring Locations

Date:	Project:	Submitter:	Reviewer:
April 2023	5635-ICE-SP-O-23	D. Kushner	K. Curtis

Figure 1

Plot 1:1 = Tabloid (L)

Dogtooth Bridge (to Kicking Horse Mountain Resort)

0+500

0+000

CPR Bridge (0+200)

Columbia River

0+500

2

Kicking Horse Dr.

9 St. N

Hwy 95

Fisher Rd.

1+000

Ramp / Boat Launch Can Provide Equipment Access to River

WSC Station 08NA006 (Active Since 2001) (1+300)

1+500

A

Pedestrian Bridge (1+700)

Gould's Island Side Channel

Gould's Island

C

Hwy 95 Bridges (2+000)

2+000

See Inset

1

B

CPR Tracks

Golden Airport

5 St. S

6 St. S

7 St. S

8 St. S

9 St. S

10 St. S

11 St. S

12 St. S

5 Ave. S

6 Ave. S

7 Ave. S

8 Ave. S

9 Ave. S

Hwy 95 (10 Ave. S)

11 Ave. S

12 Ave. S

13 Ave. S

14 Ave. S

Hwy 1

Mouth of Canyon (3+300)

3+500

3+000

Canadian Pacific (CP) Railway Tracks

Kicking Horse River

2+500

Previous WSC Station 08NA006 (1912-1922 & 1977-2001)

Bowle-Evans Dr.

1 : 10,000 metres
100 0 100 200
UTM83-11

Recommended River Ice Excavation Locations

1. Attempt to excavate side channel to provide flow relief around the highway bridge
2. Attempt to excavate toe of jam and / or grounded ice from within gravel bars. Excavation within the thalweg (deepest part of the river cross section) may be the most successful.

Recent MoTI Response Experience

A. During the December 2021 ice jam, MoTI excavated a trench through the ice jam from the inlet of Gould's Island Side Channel to station 1+400 on the main channel. The excavator worked from the top of dike. Ice jam levels were reduced at the bridge.

B. During the December 2021 ice jam, MoTI worked from the upstream edge of Gould's Island to remove ice from the main channel and side channel.

C. During the December 2022 ice jam, MoTI excavated ice from just upstream of the bridge. Several trees were cleared to provide access for the excavator from CP land to the north bank. The south abutment of Bridge 1 was accessed from Gould's Island. Ice floes that were pressing against the bridge girder were removed.

Reference: Orthophoto provided by The Town of Golden dated 2008 and Aerial Imagery from World Imagery.
Thalweg location as per site observations by Matrix Solutions Inc. in October 2022.

N

Kicking Horse River

Potential Access from CP Land to the North Bank Upstream of the Bridge

2+000

Bridge 1 Over the Main Channel

1

Access to the Upstream Edge of Gould's Island Side Channel

Bridge 2 Over the Side Channel

Access to the Upstream Edge of Gould's Island Side Channel

1 : 2,500 metres
25 0 25 50
UTM83-11

Highway 95 Bridge and Gould's Island Side Channel
Scale 1:2,5000

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

LEGEND

- Recommended River Ice Excavation Location
- Potential River Access
- Town of Golden Ice Monitoring Station
- Climate / WSC Station
- 2022 Thalweg
- 1+500 Kicking Horse River Chainage, measured from 0+000 at Confluence with Columbia River and Based on Current River Alignment

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

British Columbia Ministry of Transportation and Infrastructure
Highway 95 Bridges - Kicking Horse River - Ice Monitoring and Response Plan

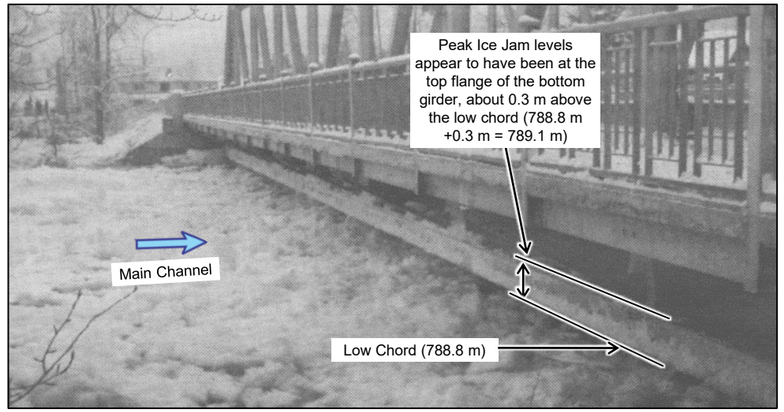
Location Plan of Recent and Recommended Response Locations in Town

Date:	Project:	Submitter:	Reviewer:
April 2023	5635-ICE-LP-23	D. Kushner	K. Curtis

Figure 2

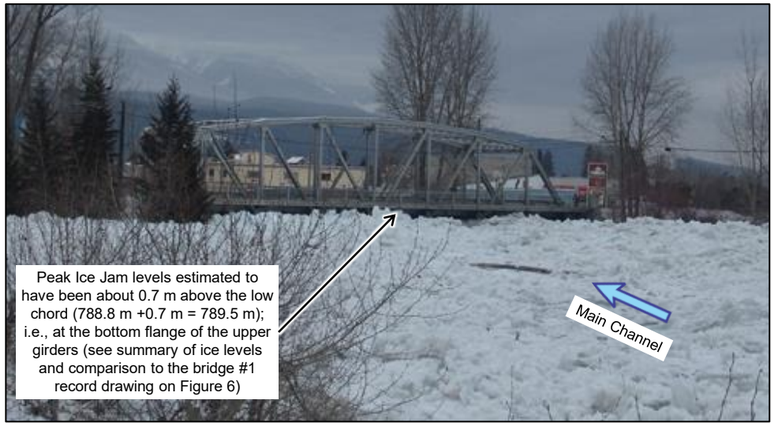
F:\5635\Drafting\20230635-ICE-LP-23.dwg - LP - April 21, 2023 3:22:12 PM - Gary Evenson

Ice Jam 1 – 2nd Highest Ice Jam
Winter of 2004/05 – January 7, 2005



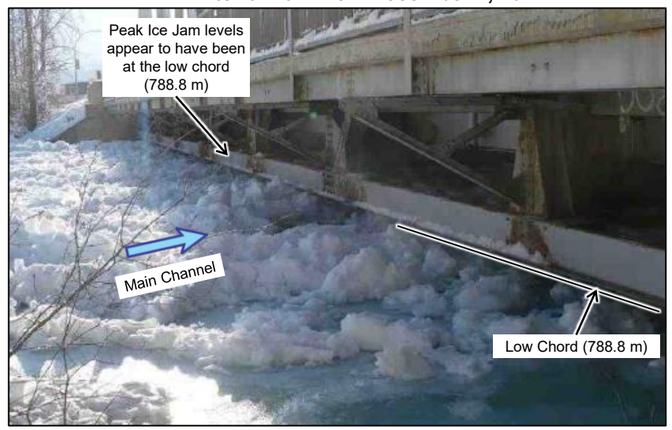
Looking at the upstream edge of Bridge 1. Photo by A. Lewandowski (Golden Star) taken on January 7, 2005 (the same day as the peak of the ice jam). The newspaper caption noted that "ice beat the underside of Golden's main bridge for close to 10 minutes".

Ice Jam 2 – Ice Jam of Record
Winter of 2005/06 – December 20, 2005



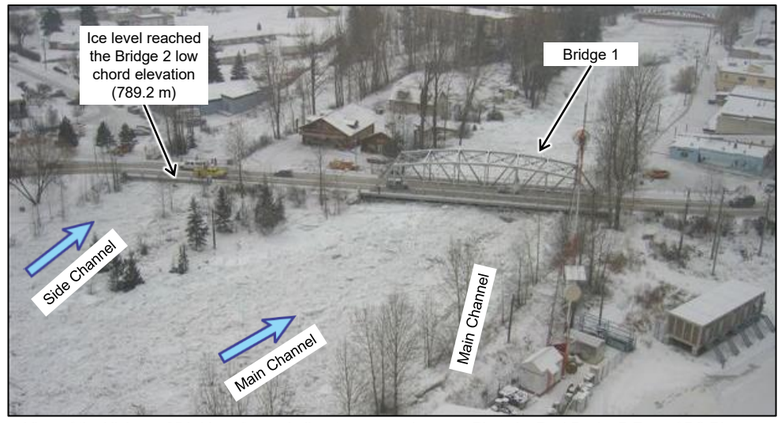
Looking at the upstream edge of Bridge 1. Photo by Paul Doyle, P.Eng. of BC Rivers Consulting (formerly of BC of Ministry of Forests Lands and Resource Development) taken on December 20, 2005 (the same day as the peak of the ice jam).

Ice Jam 3
Winter of 2014/15 – December 2, 2014



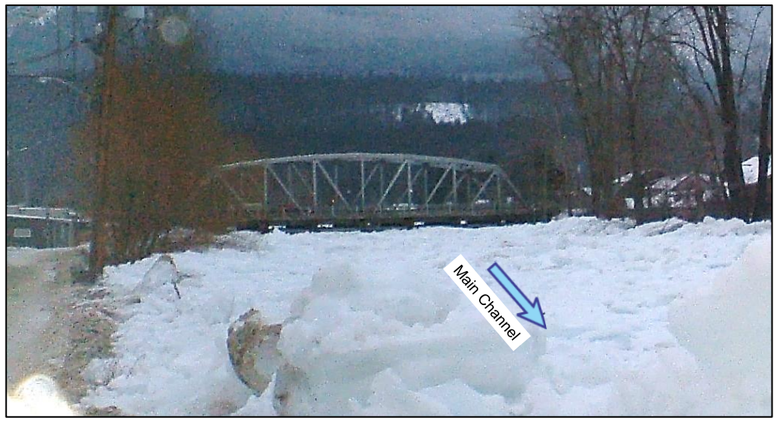
Looking at the upstream edge of Bridge 1. Photo by MoTI taken December 2, 2014 (the same day as the peak of the ice jam)

Ice Jam 2 – Ice Jam of Record
Winter of 2005/06 – December 20, 2005



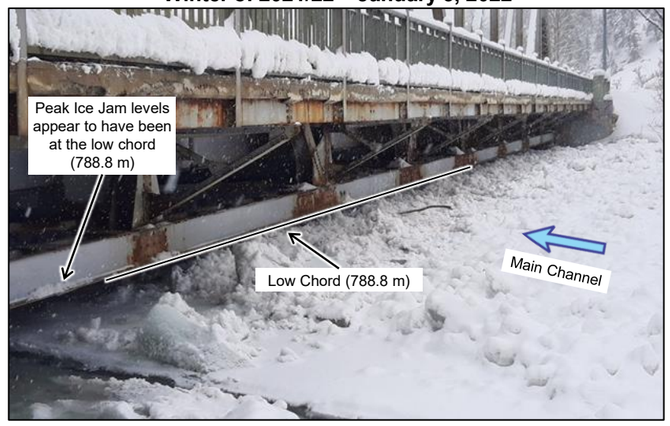
View of the Highway 95 bridges from a helicopter reconnaissance. Photo by Paul Doyle, P.Eng. of BC Rivers Consulting (formerly of BC of Ministry of Forests Lands and Resource Development) taken on December 20, 2005 (the same day as the peak of the ice jam).

Ice Jam 2 – Ice Jam of Record
Winter of 2005/06 – December 20, 2005



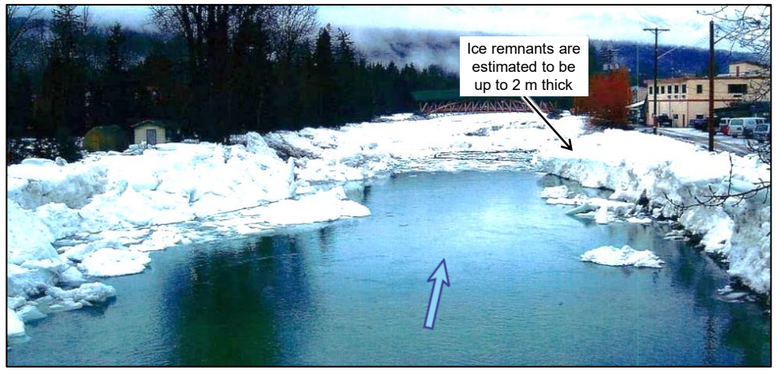
Looking at the downstream edge of Bridge 1. Photo by Paul Doyle, P.Eng. of BC Rivers Consulting (formerly of BC of Ministry of Forests Lands and Resource Development) taken on December 20, 2005 (the same day as the peak of the ice jam).

Ice Jam 4
Winter of 2021/22 – January 3, 2022



Looking at the upstream edge of Bridge 1. Photo by MoTI taken on January 3, 2022 (the same day as the peak of the ice jam). The ice jam initial occurred on December 31, 2021. Ice levels at the bridge rose to a peak on January 3, 2022.

Ice Jam 2 - Ice Jam of Record
Winter of 2005/06 – After Break-up



Looking downstream from Bridge 1. Photo provided by the Town of Golden following the December 20, 2005 ice jam (exact photo date unknown).

Four Highest Ice Levels Observed at The Bridges

Date	Winter of	Ice Jam ID	Peak Ice Level at Bridge 1
January 7, 2005	2004/05	Ice Jam 2 – Ice Jam of Record	789.1 m (0.3 m above low chord)
December 20, 2005	2005/06	Ice Jam 1 – 2nd Highest Ice Jam	789.5 m (0.7 m above low chord)
December 2, 2014	2014/15	Ice Jam 3 – 3rd / 4th Highest Ice Jam	788.8 m (at low chord)
January 3, 2022	2021/22	Ice Jam 4 – 3rd / 4th Highest Ice Jam	788.8 m (at low chord)

Also see Figure 4 for ice levels compared to the existing bridge cross section.

Notes:

1. This figure shows photographs of the four highest river ice levels observed at the bridges. Notes were added by Matrix Solutions Inc. to the photographs.
2. These ice jams initiated downstream of the bridges (not on the bridges) and extended upstream past the bridges from the accumulation of inflowing ice.
3. The highest ice level (Ice Jam 2) occurred during the December 20, 2005 ice jam event with an estimated ice level of 789.5 m at Bridge 1 (0.7 m above the low chord elevation). This ice jam included brash ice floes which are solid pieces of ice; for example, solid ice that forms along the borders of the river.
4. Bridge 1 and Bridge 2 low chord elevations surveyed by Stantec in September 2020.
5. Also see the summary of river ice levels compared to the Bridge 1 record drawing on Figure 4.
6. Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

Legend

Flow Direction

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

British Columbia Ministry of Transportation and Infrastructure

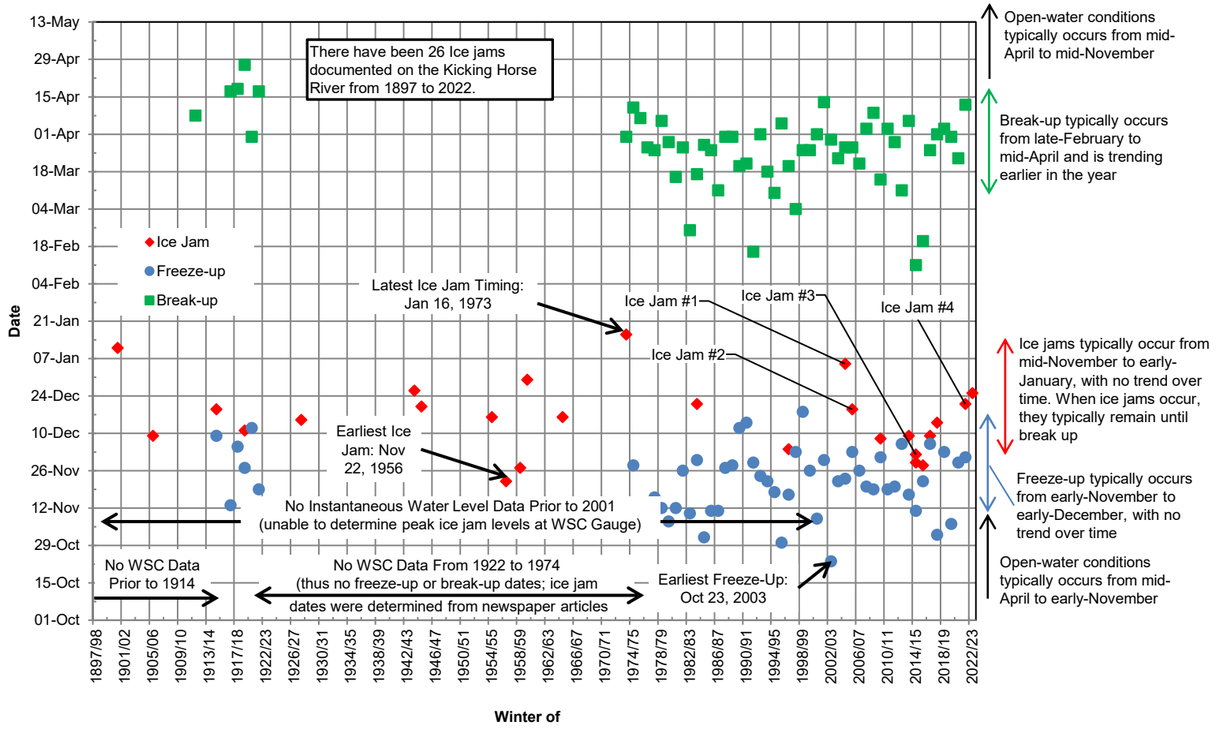
Highway 95 Bridges – Kicking Horse River – Ice Monitoring and Response Plan

Photographs of the Four Highest River Ice Levels Observed at the Bridges

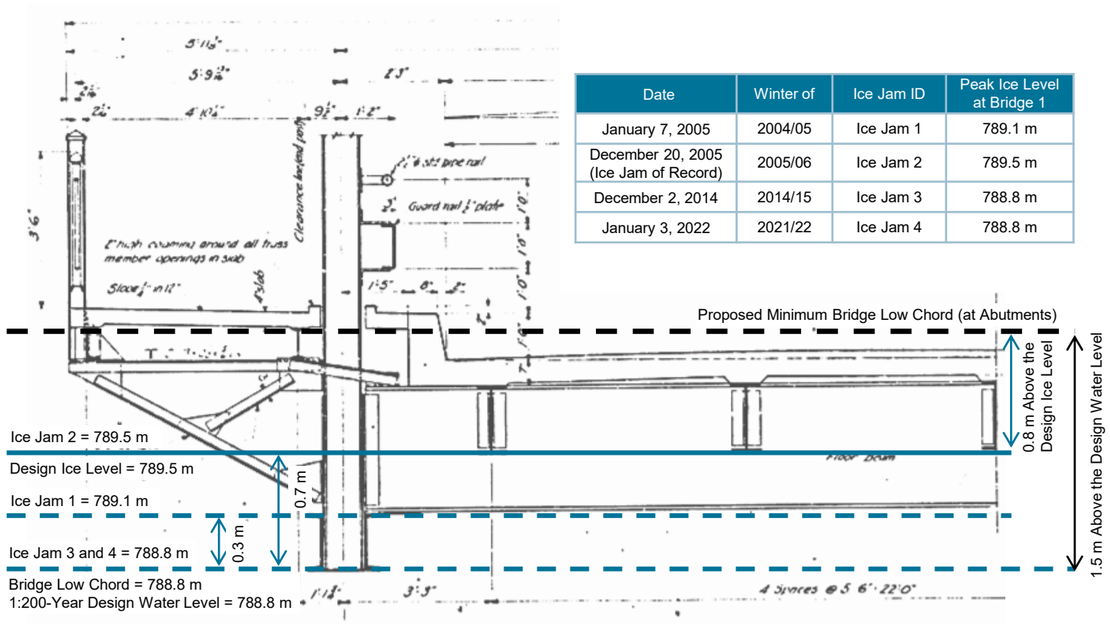
Date:	Project:	Submitter:	Reviewer:
March 2023	5635-HA	K. Seasons	D. Kushner

Figure 3

Freeze-Up, Ice Jam, and Break-Up Dates at Water Survey of Canada (WSC) Gauge (See Note 1)

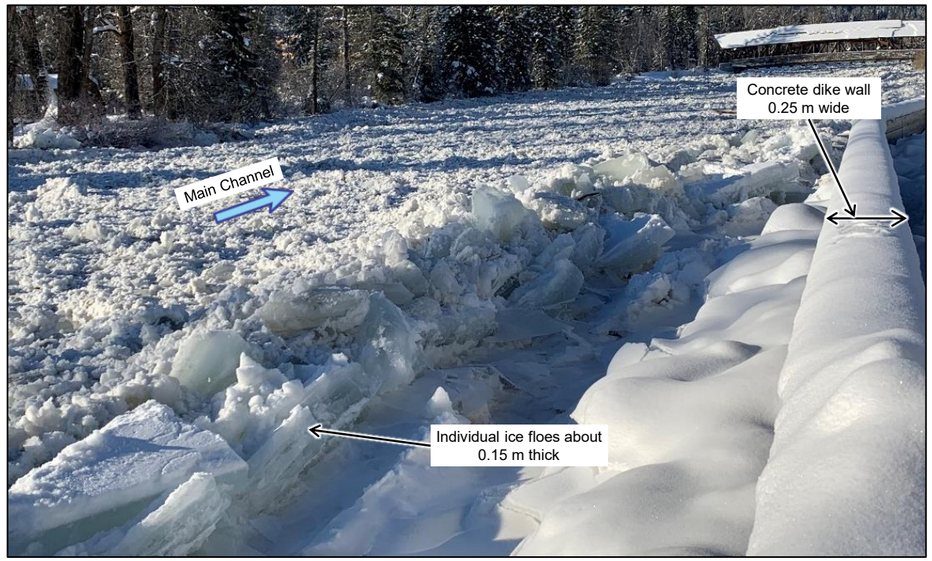


Four Highest Observed River Ice Levels Superimposed on the Bridge 1 Record Drawing



Date	Winter of	Ice Jam ID	Peak Ice Level at Bridge 1
January 7, 2005	2004/05	Ice Jam 1	789.1 m
December 20, 2005 (Ice Jam of Record)	2005/06	Ice Jam 2	789.5 m
December 2, 2014	2014/15	Ice Jam 3	788.8 m
January 3, 2022	2021/22	Ice Jam 4	788.8 m

Typical Ice Floe Thickness



Typical example of ice floe size. Photo taken by MoTI on January 3, 2022.

Typical Border Ice Cover

Highway 95 Bridge 1 visible in background. Border ice has formed a solid ice cover on the river at low elevation. Photo taken by the Town of Golden on February 8, 2021.

Legend

Flow Direction

Notes:

1. Freeze-up dates, break-up dates, and peak ice jam levels are from Water Survey of Canada (WSC) hydrometric station 08NA006, located on the Kicking Horse River at the town of Golden. Ice jam dates were determined from the WSC data and newspaper articles per Matrix 2018 *Kicking Horse River Ice Jam Study*.
2. Ice jam levels at Bridge 1 are estimated from the photographs on Figure 3 and scaled on the bridge record drawing relative to the low chord elevation.
3. Bridge 1 low chord elevation surveyed by Stantec in September 2020.
4. Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

British Columbia Ministry of Transportation and Infrastructure

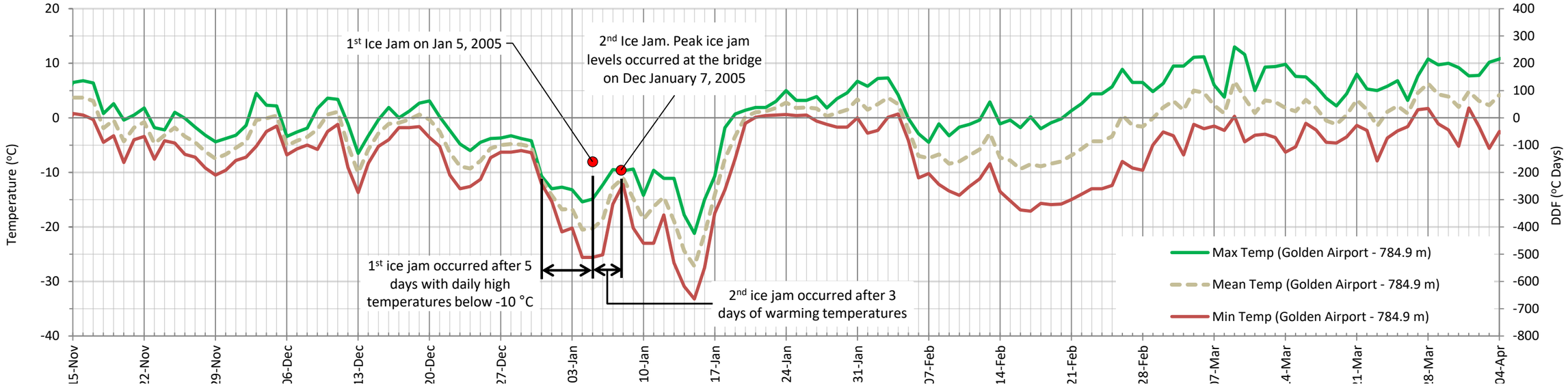
Highway 95 Bridges – Kicking Horse River – Ice Monitoring and Response Plan

Typical River Ice Photographs and Historical Ice Jam Timing

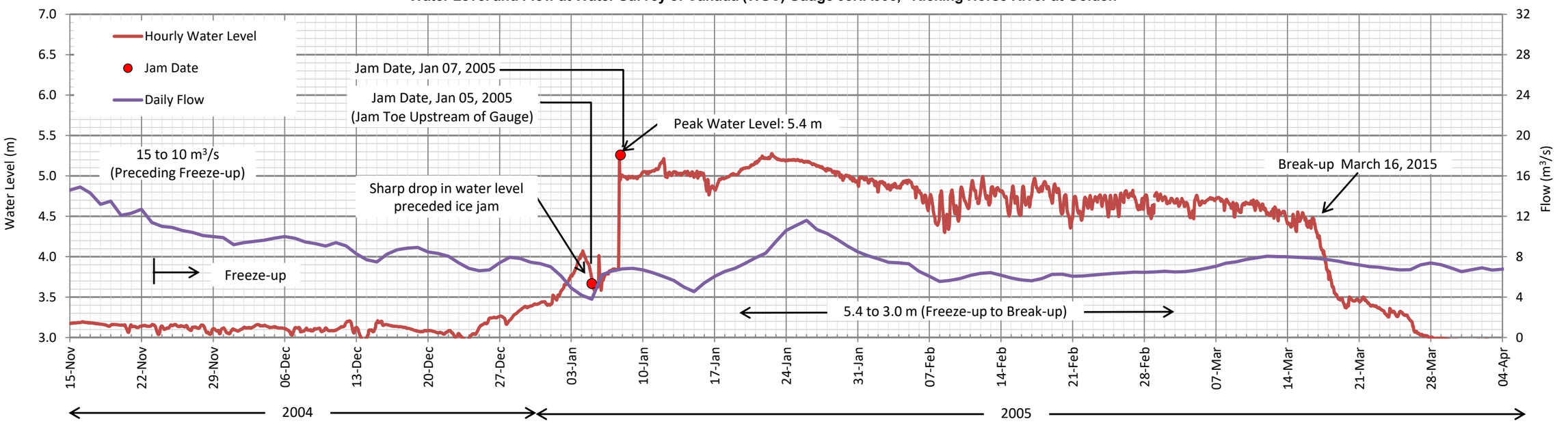
Date:	Project:	Submitter:	Reviewer:
March 2023	5635-HA	K. Seasons	D. Kushner

Figure 4

Temperature (at Golden Airport and Ministry of Transportation (MOT) Station at 10 Mile Hill)



Water Level and Flow at Water Survey of Canada (WSC) Gauge 08NA006, "Kicking Horse River at Golden"



Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

British Columbia Ministry of Transportation and Infrastructure

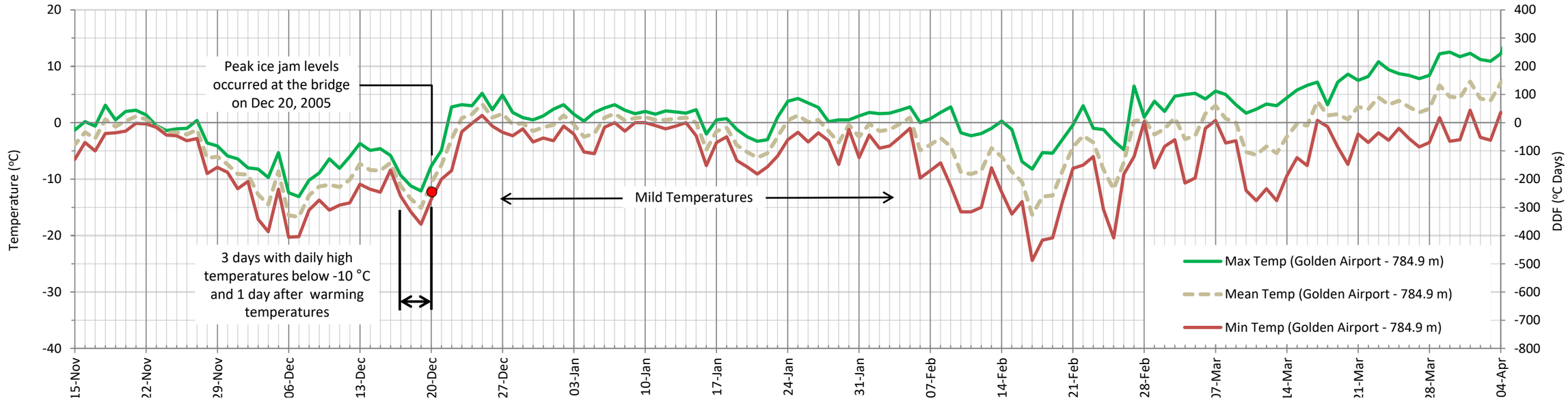
Highway 95 Bridges – Kicking Horse River – Ice Monitoring and Response Plan

Temperature and WSC Data
Winter of 2004 / 2005
2nd Highest Ice Jam at Bridges

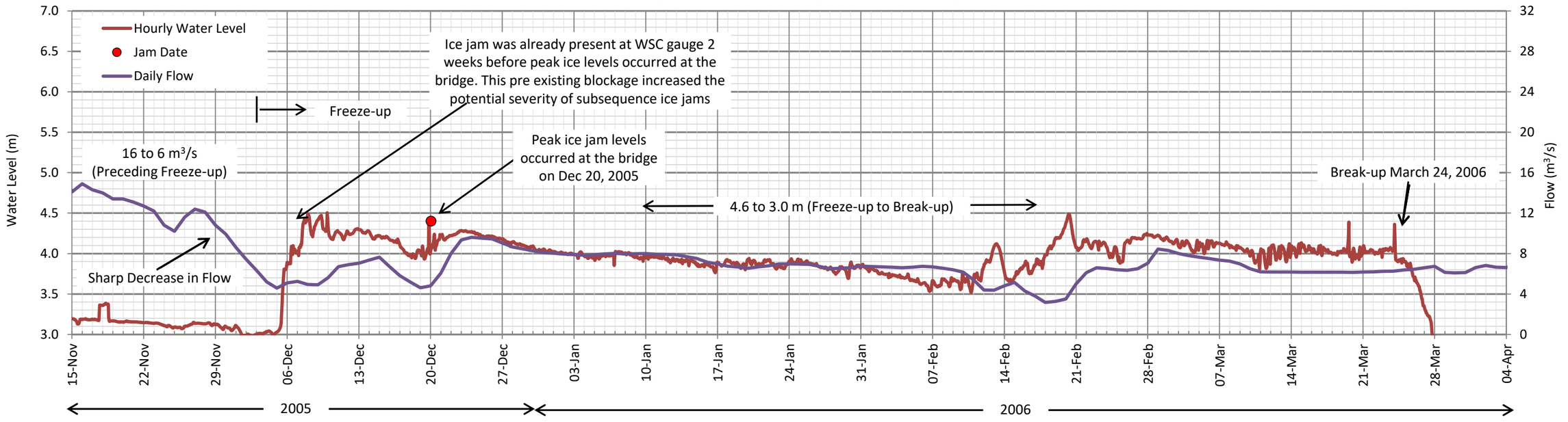
Date:	Project:	Submitter:	Reviewer:
March 2023	5635-HA	K. Seasons	D. Kushner

Figure 5

Temperature (at Golden Airport and Ministry of Transportation (MOT) Station at 10 Mile Hill)



Water Level and Flow at Water Survey of Canada (WSC) Gauge 08NA006, "Kicking Horse River at Golden"



Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

British Columbia Ministry of Transportation and Infrastructure

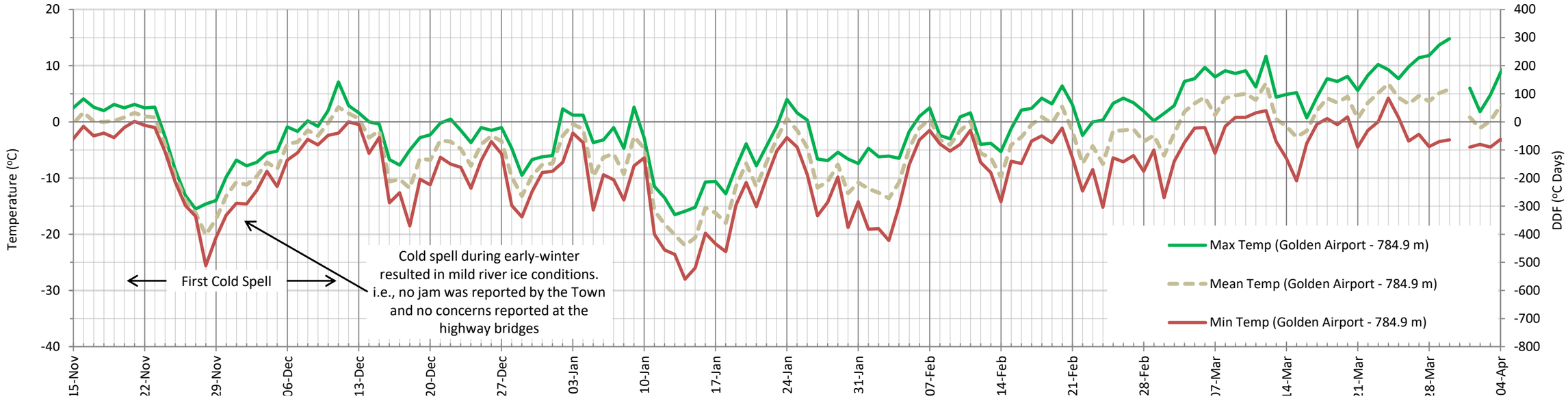
Highway 95 Bridges – Kicking Horse River – Ice Monitoring and Response Plan

Temperatures and WSC Data
Winter of 2005 / 2006
Highest Ice Jam at Bridges (Ice Jam of Record)

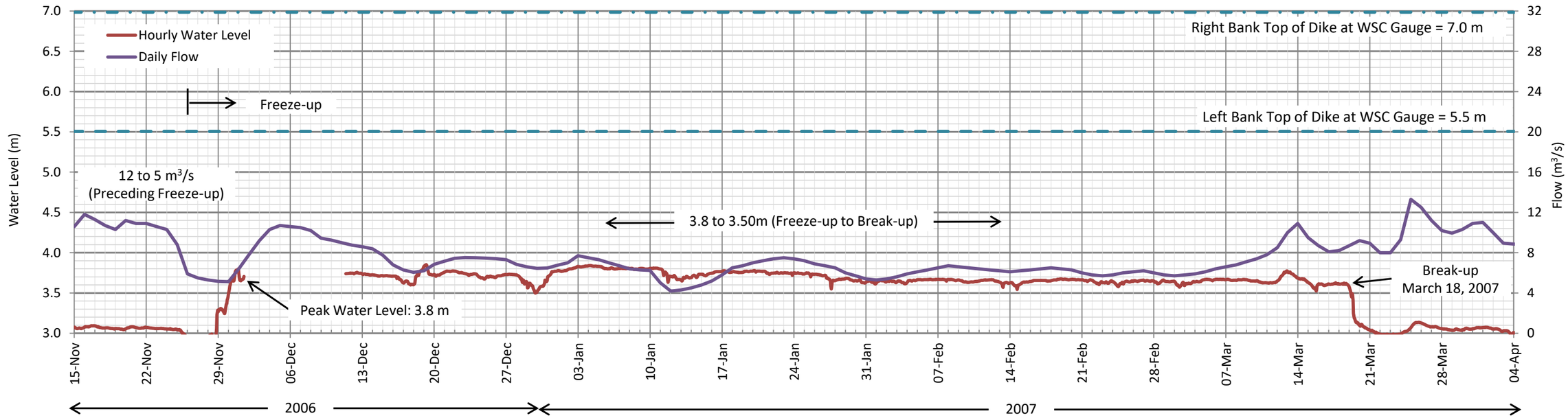
Date:	Project:	Submitter:	Reviewer:
March 2023	5635-HA	K. Seasons	D. Kushner

Figure 6

Temperature (at Golden Airport and Ministry of Transportation (MOT) Station at 10 Mile Hill)



Water Level and Flow at Water Survey of Canada (WSC) Gauge 08NA006, "Kicking Horse River at Golden"



Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

British Columbia Ministry of Transportation and Infrastructure

Highway 95 Bridges – Kicking Horse River – Ice Monitoring and Response Plan

Temperatures and WSC Data
Winter of 2006 / 2007
No Ice Jam Reported

Date:	Project:	Submitter:	Reviewer:
March 2023	5635-HA	K. Seasons	D. Kushner

Figure 7

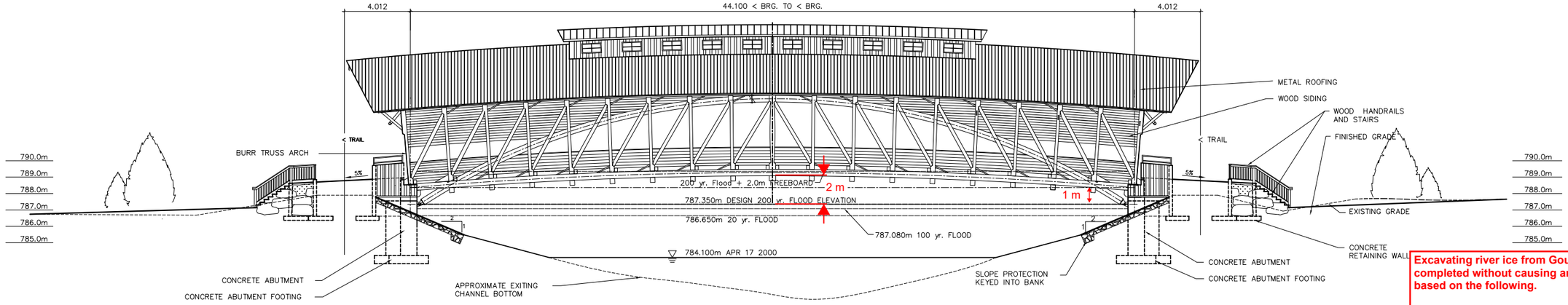
British Columbia Ministry of Transportation and Infrastructure

Highway 95 Bridges - Kicking Horse River - Ice Monitoring and Response Plan

Markup of Pedestrian Bridge Drawing

Figure: 8

Matrix Solutions Inc.
March 2023



Excavating river ice from Gould's Island side channel can likely be completed without causing any issues at the pedestrian bridge, based on the following.

The pedestrian bridge was not damaged during the 2005 ice jam of record; See Photo Below (the pedestrian bridge was constructed in 2001).

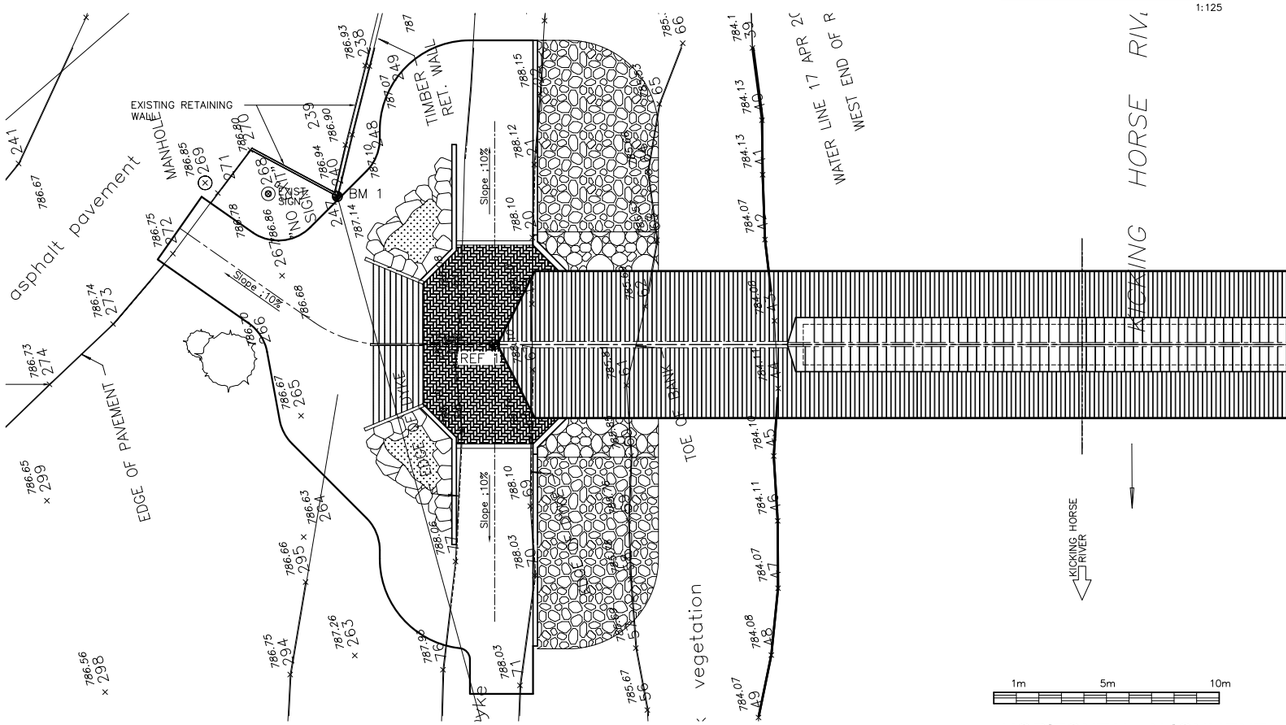
The pedestrian bridge is 1 m higher at the abutments and 2 m higher at mid span compared to the existing Highway 95 Bridge 1, relative to the 1:200-year water level. In other words the pedestrian bridge provides up to 2 m more clearance compared to the Highway 95 Bridge 1.

Photograph of the ped bridge during the 2005 ice jam of record

1m 5m 10m

VERTICAL ALIGNMENT

1:125



1m 5m 10m

HORIZONTAL ALIGNMENT

1:125

SURVEY CONTROL DATA

STA.	NORTHING	EASTING	ELEVATION	REMARK
EXISTING MONUMENTS				
BM1	633.307m	513.645m	787.140m	RET. WALL BASE
BM2	574.308m	474.423m	787.870m	TBM
NEW CONTROL POINTS				
REF 1	628.309m	505.464m	788.800m	TRAIL/BRIDGE <
REF 2	578.036m	491.695m	788.800m	TRAIL/BRIDGE <

NOTES

1. SURVEY INFORMATION IS BASED UPON INFORMATION PROVIDED BY W.E. MADDOX, B.C. LAND SURVEYOR.
2. 200 YEAR FLOOD ELEVATION IS INTERPOLATED FROM HYDROCONSULT ENG SERVICES LTD. INFORMATION PROVIDED BY THE TOWN OF GOLDEN.
3. ALL ELEVATIONS ARE IN METRES AND DECIMALS THEREOF UNLESS NOTED.
4. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED.
5. SEE DWG. SS-1 FOR GENERAL NOTES.
6. 786.23 x INDICATES EXISTING GRADE ELEVATION (ADD 700m TO EACH VALUE)

No.	Revision/Issue	Date
	RE-ISSUED	01/07/23

Consultant

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T1W 1Z7
Ph. (403) 678-3746
Fax. (403) 678-5892
e-mail: rcostley@telusplanet.net

Drawing

Burr Arch (Contemporary Version) GENERAL ARRANGEMENT

Project

Pedestrain Bridge Over Kicking Horse River

Golden, British Columbia

Project No. 00117
Sheet S-2
Date 01/01/22
Scale as noted

TABLE 1 Summary of Ice Jam Risk Factors

Level of Importance / Factors to Consider		Higher Risk Examples	Low to no Risk Examples
1	**Time of Year** • Ice jams typically occur from mid-November to early-January. • Very low risk before November or after January.	Mid-November to early-January.	Before November. After January.
1	**Conditions at Highway 95 Bridge** • If there is low freeboard or the bridge is currently loaded by an ice jam.	Ice jam is currently at or above the bridge low chord and may be loading the bridge.	Large freeboard remaining from bridge low chord to water / river ice level.
2	**Air Temperature & Weather** • Ice generation is driven by cold temperatures (< 0°C). • Lower temperatures for many consecutive days increase the risk of ice jams occurring. • Warming temperatures and sunny days may trigger release ice from the canyon upstream of the town.	Long period of cold temperatures (e.g., < -10 °C for 5 or more consecutive days). Long period of cold temperatures followed by warm (> 0°C) and sunny days.	Mild temperatures have occurred and are expected to continue (e.g., -5 to +5 °C).
3	**Conditions In Canyon** • More ice volume increases the potential ice jam severity (if this ice were to be released) • More ice cover increases the resistance of ice being released, thus decreases ice jam likelihood. • More open water results in increased frazil ice generation (increased risk if cold air temperatures also occur)	Solid ice cover with little open water.	Little ice cover and many sections of open water, but some localized areas with large volumes of ice.
3	**Conditions in Town and on Columbia River** • Previous ice jams, strong solid ice cover, or other blockages increase the likelihood that incoming ice floes will jam in the Town or at the bridges.	Solid, thick, and complete ice cover of the Kicking Horse or Columbia rivers. Ice jam present on the Kicking Horse or Columbia rivers, and the ice jam has solidified / strengthened from many days of cold weather.	Incomplete, thin ice cover on the Kicking Horse or Columbia rivers. Low elevation, thin ice jam is present on the Kicking Horse or Columbia rivers, that may be cleared out by subsequent ice jams
4	**Water Temperature** • Frazil ice generation risk is increased when the water is supercooled (< 0°C). • Note that the Town of Golden Ice monitoring system includes a river temperature sensor.	Water is supercooled (< 0°C)	Water temperatures are high (> 0°C or higher)