Hydrologic and Geomorphic Assessment of the Dore River

March 11, 2021 | Revision 2

Submitted to: Regional District of Fraser-Fort George
Prepared by McElhanney Ltd. with contributions from BGC Engineering Inc.

Contact
Stephanie Wall
778-763-0998
swall@mcelhanney.com

Address
12 – 556 North Nechako Road, Prince George BC Canada, V2K 1A1

Our file: 2341-21107-00

Your Challenge.
Our Passion.

Contents

Tables

Figures

Appendices

1. Executive summary

A large rainstorm on June 23/24, 2020 coupled with runoff from snowmelt, resulted in extreme flows in the Dore River. Significant bank erosion occurred between the Highway 16 bridge and the Canadian National Railway bridge during this event. Multiple properties on Dorval Road, located adjacent to the right (east) bank of the river lost significant portions of their property to this erosion.

The Regional District of Fraser-Fort George (RDFFG, the District) requested that McElhanney Ltd. (McElhanney) provide a more detailed assessment or the Dore River at this location (area of interest AOI). The objectives of the assignment included:

- Hydraulic assessment of the current and anticipated flood impact threat of the Dore River to resident public safety and property;
- Provide decision support to local government EM response plan for immediate response and public safety alerting triggers;
- Provide site options for deployment of temporary flood protection measures and long-term permanent infrastructure options;
- Consolidation of work done by various stakeholders on the condition of the Dore River that would support post event planning and synchronize shoreline mitigation projects;
- Potential locations for additional fixed monitoring and options for enhanced localized public safely notifications, where hazardous conditions are present; and
- Identification of temporary debris management sites near the Dore River for increased construction and demolition waste as recovery begins.

To meet these objectives, McElhanney, teaming with BGC Engineering Inc. (BGC), agreed with the District to the following Scope of Work:

- Complete LiDAR acquisition and a detailed channel survey.
- Complete a hydrologic analysis for flows on the Dore River to predict the flows for various return periods. The potential effects of climate change on the predicted flows will also be assessed.
- Develop a 2-dimensional (2D) hydraulic model of the Dore River in the study area.
- Complete an assessment of bank erosion and channel change of the Dore River within the study reach and develop a probabilistic model to predict the magnitude of future erosion events.
- Complete regional scale assessment of upper Dore River watershed geomorphology as it relates to potential downstream flood concerns within the AOI, including the classification of tributaries prone to debris floods or debris flows, and identification of deep-seated landslides that could cause temporary blockages of the main watercourse.

The results from the various components in the Scope of Work were then reviewed and recommendations were provided relating to the projects objectives.

2020 Dore River Flood Event

A peak flow of 169 m^3/s was recorded during afternoon of June 23rd, 2020 at the Water Survey of Canada gauging station on the Dore River. This corresponds to a 70-year to 100-year return period event for the watershed. This event resulted in significant bank erosion on the right bank of the river within the study reach. Approximately 1.2 hectares of land was lost to erosion, with the Dore River's thalweg laterally migrating up to 50 m at some locations.

A second, sperate extreme flood event occurred September 1-3, 2020. This flood event had a peak flow of 148 m^3/s which is equivalent to a 25-year return period flood event. Despite the high flows, minimal additional bank erosion occurred in the study reach.

Bank Erosion Assessment

Remote sensed imagery (e.g. air photos from 1946 – 2020, satellite and drone images) were analyzed to evaluate channel changes in the subject reach of the Dore River. Air photo analysis showed the Dore River was modified between 1958 and 1976. River modifications during this period included channel realignment, rip rap bank armouring at various locations, and the construction of berms.

Bank erosion modelling was performed to estimate the magnitude of future erosion events within the AOI. The model results predicted future erosion during a 200-year flood event to be in the range of 10 m – 60 m based on the extent and locations of deposits in the river in October 2020. Erosion will likely concentrate at the outside of existing bends and continue to increase the re-meandering of the river.

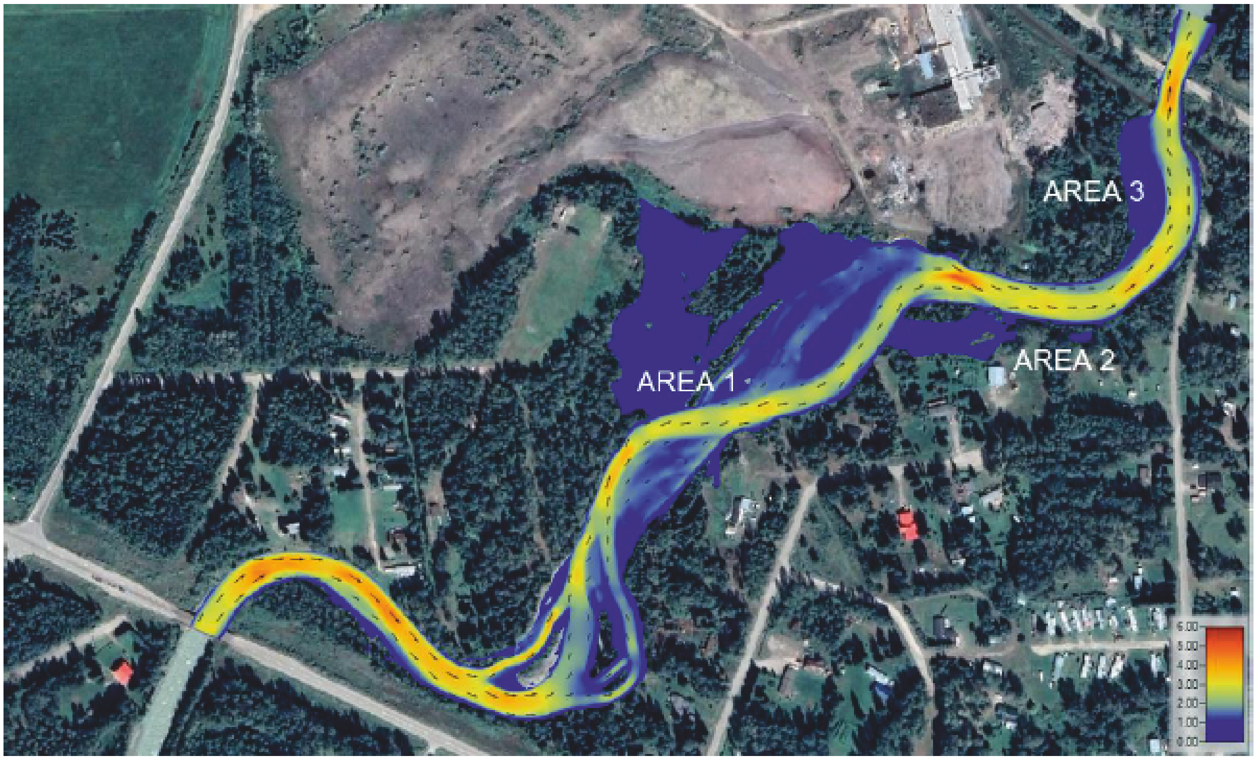
Hydrology

A flood frequency analysis was performed on the flow record from a WSC (Water Survey of Canada) stream gauging station (Dore River near McBride - #08KA001) located approximately 2 km upstream of the project location. The gauge measures river level, and the corresponding flow, in the Dore River. It has been operating continuously 58-year flow record and captured the flows during the 2020 events. The results of the analysis are presented in the table below.

Return Period (Years)	Peak Instantaneous Flow (m^3/s)
200	186
100	173
10	129
2	93

Hydraulic Model

A 2-dimensional hydraulic model was developed for the AOI. The model relied on topology derived from LIDAR and channel bathymetry information acquired after the September 2020 flood event. The 200-year return period flood event predicted 3 areas of inundation (overland flooding) shown in the figure below. The predicted water surface elevation and velocities can be used as design parameters for subsequent detailed designs.



Watershed Geomorphic Overview

A qualitative desktop level overview of the Dore Rover watershed, upstream of developed areas, was completed to identify, at an overview level of detail, geomorphic processes occurring within the watershed that could influence downstream flood hazard or channel characteristics within the AOI. Geohazards identified within the watershed include snow avalanches, clear-water floods, steep creek processes (debris flows, debris floods), rock slides and rock fall on steep, upper valley slopes. Landforms interpreted as deep-seated slope movement were also identified where large enough (on the order of many tens to hundreds of thousands of cubic metres) to potentially result in a type of channel blockage referred to as landslide dam, with implications for downstream flooding. While deep-seated slope movement landforms were identified in multiple locations within the upper watershed, no identifiable surface evidence showed landslide dam impoundments or outbreak floods in recent times (since 1947). This indicates that the historic return period of landslide impoundments is likely greater than 100 years. An outbreak flood that was the result of a snow avalanche channel blockage occurred on May 26, 1986. It results in destruction of upstream forestry bridges and other damage.

Based on the presence of abundant slope-scale landslide landforms and valley geometries that are confined enough for river blockage, BGC concludes that the potential exists for landslide dams to form and fail, with potential for elevated flood or debris flood discharge that could reach the AOI. There is also potential for elevated flood discharges to occur following the formation and failure of (mostly wet spring) snow avalanche dams.

Conclusions

The Dore River experienced a 100-year flood event on June 23, 2020 resulting in significant erosion in the channel. Previous engineering works completed in 1958 – 1976 narrowed and straightened the river, resulting in higher flow velocities and shear stress for a given flood flow and amplified the erosion.

Given the current channel morphology, the Dore River in the AOI has a larger hydraulic capacity than it did prior to the June 2020 flood event. There is still a risk of future bank erosion. Should erosion mitigation and bank protection options be considered within the AOI, the designs should maintain the wider river geometry and work with – rather than against – the natural tendency of the river to meander.

2. Introduction

The Dore River, a tributary to the Fraser River, is located approximately 4 km northwest of McBride, BC. A large rainstorm on June 23/24, 2020, coupled with snowmelt, resulted in extreme flows in the Dore River. Significant bank erosion occurred between the Highway 16 bridge and the Canadian National Railway bridge during this storm event. Multiple properties on Dorval Road, located adjacent to the right (east) bank of the river lost significant portions of their property to this erosion. As part of the emergency response in the aftermath of that flood event, the Regional District of Fraser-Fort George (RDFFG, the District) requested McElhanney Ltd. (McElhanney) to provide engineering support (inspection, reporting) on recovery activities that were occurring. McElhanney project engineer Lucy Swank was on-site July 1st, 2020. A summary of the activities completed and McElhanney's initial assessment of the study area is provided in a Technical Memo dated July 3, 2020 and is included in Appendix A.

Subsequent to these activities in September 2020, the District retained McElhanney to provide a more detailed assessment of the section of Dore River between the Highway 16 bridge and the CNR Bridge. McElhanney teamed with BGC Engineering Ltd to provide the required services. The objectives of this assignment included:

- Hydraulic assessment of the current and anticipated flood impact threat of the Dore River to resident public safety and property;
- Provide decision support to local government EM response plan for immediate response and public safety alerting triggers;
- Provide site options for deployment of temporary flood protection measures and long-term permanent infrastructure options;
- Consolidation of work done by various stakeholders on the condition of the Dore River that would support post event planning and synchronize shoreline mitigation projects;
- Potential locations for additional fixed monitoring and options for enhanced localized public safely notifications, where hazardous conditions are present; and
- Identification of temporary debris management sites near the Dore River for increased construction and demolition waste as recovery begins.

To meet these objectives, the District and the project team agreed to the following Scope of Work:

- Complete LiDAR acquisition and a detailed channel survey.
- Complete a hydrologic analysis for flows on the Dore River to predict the flows for various return periods. The potential effects of climate change on the predicted flows will also be assessed.
- Develop a 2-dimensional (2D) hydraulic model of the Dore River in the study area.
- Complete an assessment of bank erosion and channel change of the Dore River within the study reach and develop a probabilistic model to predict the magnitude of future erosion events.

- Complete an assessment of the Upper Dore River watershed and identify potential hazard sources including:
    - Interpreting the watershed terrain, geology, and geohazards.
    - Identifying existing large landslides that could pose a landslide dam outbreak flood hazard.
    - Classify these landslides with respect to the likelihood of reaching and damming the Dore River.
    - Provide recommendations relating to watershed geomorphology in sustained flood response on the Dore River.

The results from the various components in the Scope of Work were then reviewed and recommendations were provided relating to the projects objectives.

Area of Interest

The area of interest is the 1300 m long reach of the Dore River from the Highway 16 bridge to immediately downstream of the Museum Road bridge as shown in Figure 1.

Figure 1 Dore River AOI

3. Recent Project History and the 2020 Events

The McBride area received approximately 150 mm of precipitation in between June 1st and July 3rd, 2020 as measured at the Environment Canada McBride climate station. Daily (24-hour) precipitations for the same period, presented in Figure 2, show storms of 20 mm on June 14th and June 23rd, and 23 mm on June 30th and July 1st. This precipitation, couple with snowmelt from the upper Dore River watershed, resulted in extreme flows in the Dore River.

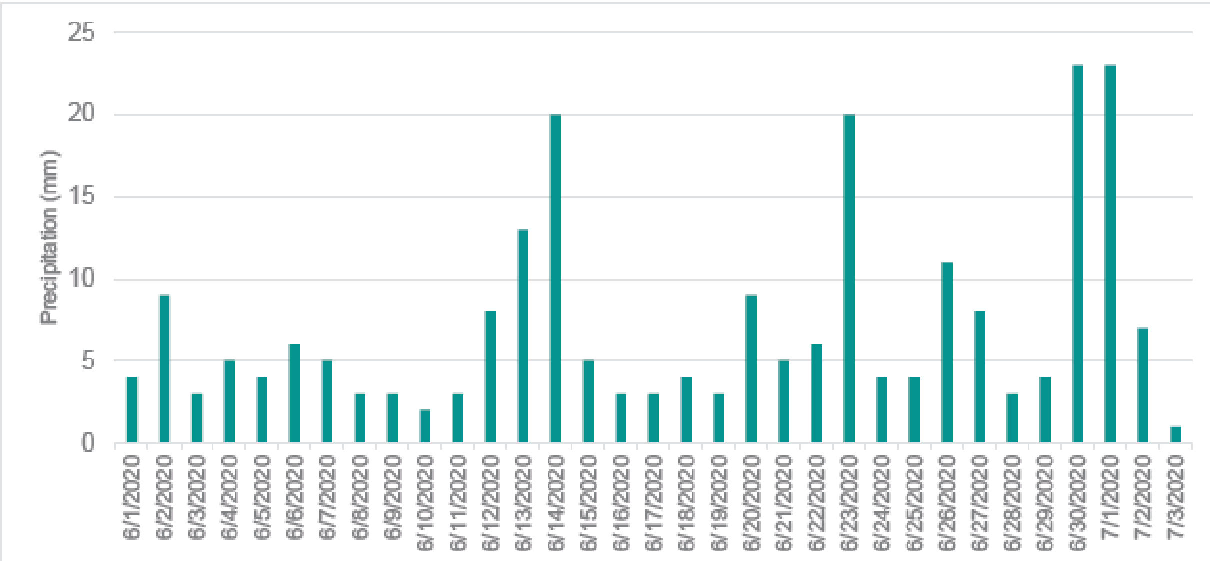


Figure 2 Daily Precipitation - June 1, 2020 to July 2, 2020 - McBride Climate Station

Figure 3 shows the preliminary flow records from the Water Survey of Canada (WSC) gauging station located 2 km upstream from the area of interest. High flows are witnessed in response to the rain events noted, with the peak instantaneous flow of 169 m^3/s recorded during afternoon of June 23rd.

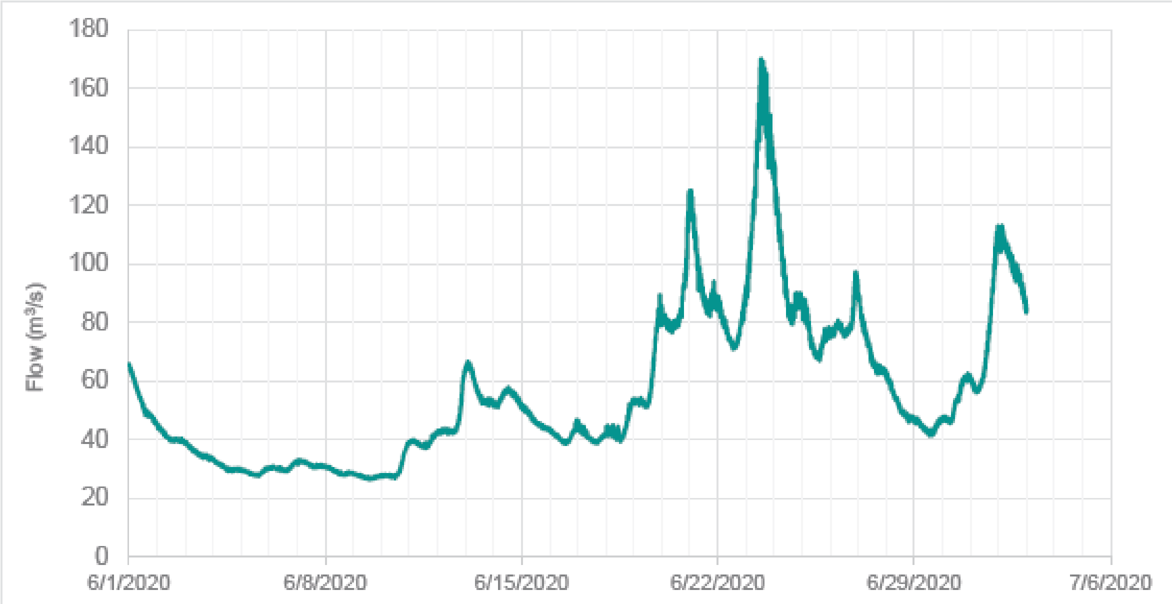


Figure 3 Flow (Preliminary) - June 1, 2020 to July 2, 2020 – WSC #08KA001: Dore River at McBride

Erosion is a natural process in mountain rivers. This process is often accelerated during extreme events due to higher water velocities (erosive force), mobilization of woody debris and bedload, and inadequate hydraulic capacity in the channel to convey the flow and debris. A log jam was present at the upstream end of the bar/island highlighted in Figure 4. Mobilized debris was deposited on the log jam increasing its size and this reduced the hydraulic capacity of the channel at this location. Significant erosion occurred at this point in the channel which increased the channel's hydraulic capacity. The result was that the river created the new channel alignment that is present today (Figure 5).

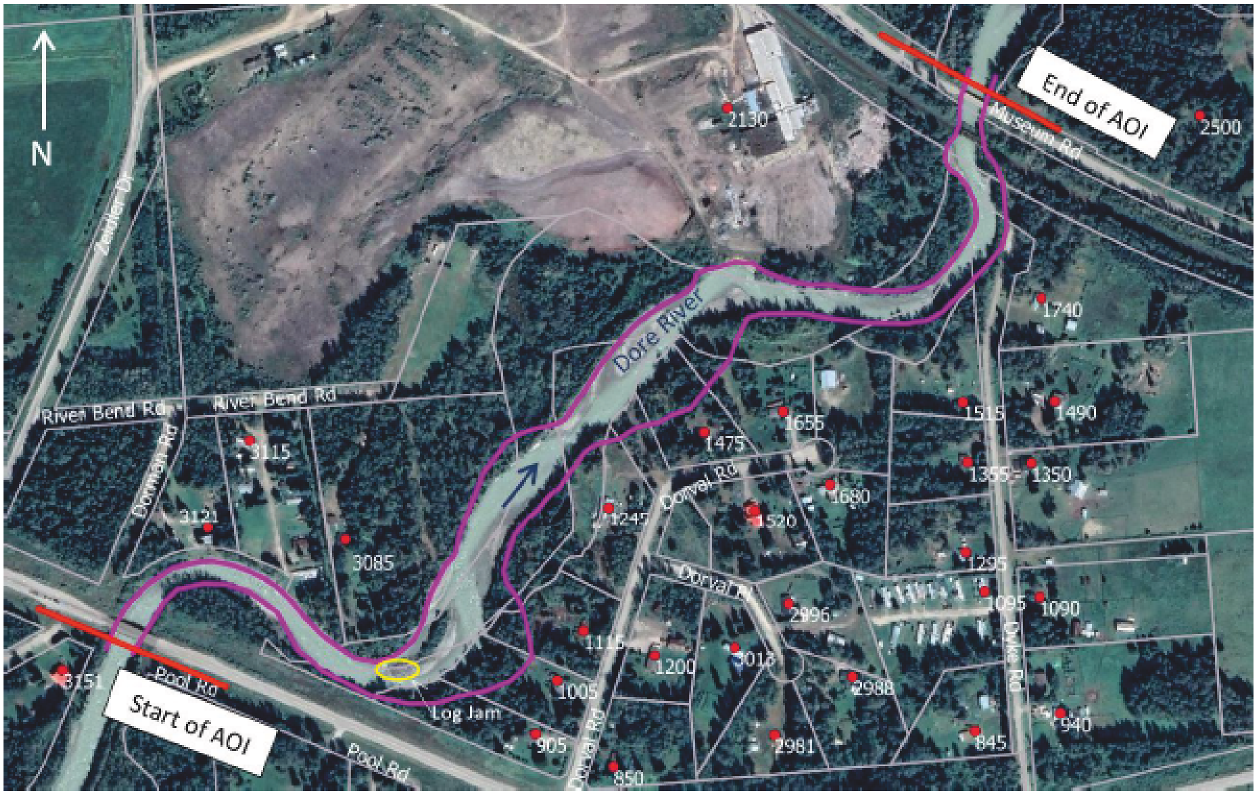


Figure 4: New channel extents overlain on Google satellite imagery of the pre-flood channel.

Figure 5: Post flood drone imagery showing new channel alignment (Drone flight occurred July 26, 2020)

Figure 6 shows the downstream side of the log jam that formed during the flood event. Log jam debris was mostly removed on July 1, 2020 to open up the channel.

Figure 6 Looking upstream toward log jam (red). Photo taken July 1, 2020.

Figure 7 shows the remaining debris post debris removal after the flood event.

Figure 7 Looking downstream towards remnants of log jam (Photo taken November 3, 2020)

Figure 8 shows the newly widened channel in front of the 1005 Dorval Road property.

Figure 8 Looking across the channel from the 1005 Dorval Road property. (Photo taken July 1, 2020)

Figure 9 shows the Dore River at high flow along the new channel formed along the 1475 Dorval Road property.

Figure 9 Looking downstream towards the 1475 and 1655 Dorval Road properties. (Photo taken July 1, 2020)

Figure 10 shows the newly eroded channel in front of the 1475 Dorval Road property at low water and the extents of this can be observed in Figure *5*.

Figure 10 Looking out toward Dore River from banks of the 1475 Dorval Road property (Photo taken November 3, 2020)

A second site visit occurred on November 3rd, 2020 to meet with the residents of the impacted properties. The residents were presented with maps of the flood area before the time of the site visit and asked to provide their observations. Residents gave detailed verbal accounts of the event during the visit. The marked-up maps with comments were passed on to the RDFFG who provided them to the consultant.

4. Hydrologic Analysis

A hydrologic analysis was performed to estimate the flow, for various return periods, in the Dore River within the AOI.

4.1. DORE RIVER WATERSHED

The Dore River watershed drains a total area of 418.7 km^2, including 411.5 km^2 upstream of the Highway 16 bridge. It is characterized by steep, mountainous, and glaciated terrain. The upper watershed is forested, with forest harvesting having occurred throughout the area. Figure 11 presents a map of the Dore River watershed.

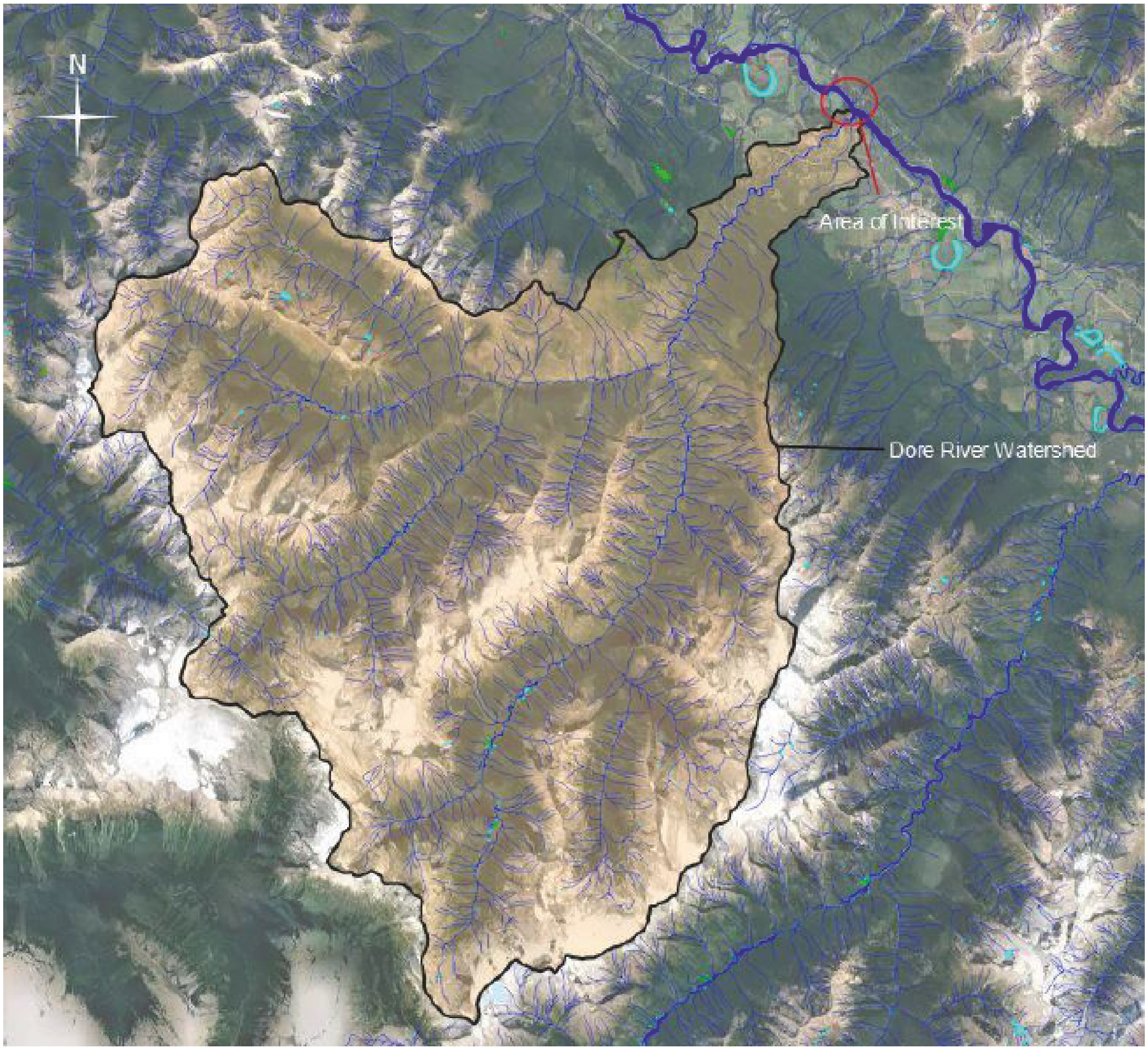


Figure 11: Dore River Watershed.

The Dore is a nival watershed whose annual peak flows are controlled by snowmelt and typically occur between late May to early July. Figure 12 presents the annual hydrographs for Dore River WSC station. Typically, the annual peak flow occurs during the spring freshet. Some large flow events, however, do occur in the late summer and early fall and are the result of large rainfalls.

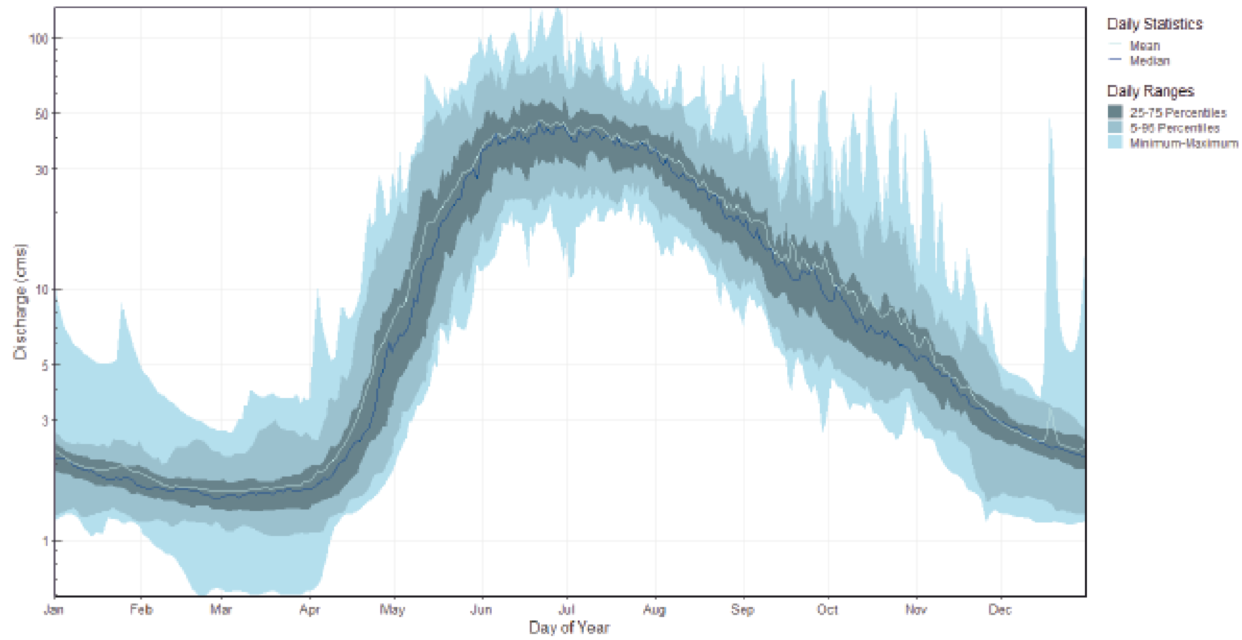


Figure 12: Annual hydrographs for Dore River WSC Station (08KA001). 1949-2013 (51 Years of Record)

4.2. FLOOD FREQUENCY ANALYSIS

A WSC stream gauging station (Dore River near McBride - #08KA001) is located approximately 2 km upstream of the project location. The gauge measures river level, and the corresponding flow, in the Dore River. It has been operating continuously 58-year flow record and captured the flows during the 2020 events.

The data recorded at the gauge has been verified by WSC up to the end of 2013. Preliminary data for the station is available to the December 2020.

Two flood frequency analyses were performed on the annual peak instantaneous flow and annual peak average daily flow data for the Dore River WSC station: one analysis relied only on the verified data (up to 2013); the second analysis included preliminary data for 2019 and 2020.

For years where only annual peak average daily flow (D) data was available, the corresponding annual peak instantaneous flow (I) was estimated by plotting the relationship between I and D for years where both were reported, then applying the regression equation of that relationship to the annual average daily peak. The statistical analysis was completed using dedicated script written in the R programming language. Publicly available algorithm packages, written to perform specific statistical analysis like data analysis, statistical distribution fitting, and graphing, were used as part of the code (*lmomco, ggplot2*). General methods employed in the flood frequency analysis included the following steps:

- Determining the L-moments for each data set;
- Fitting up to six statistical distributions to each data, including:

- General Extreme Value (GEV);
- Three Parameter Log-normal (3LN);
- Log-Pearson Type III (LP3);
- Wakeby (WAK);
- Gumbell (EV1); and
- Generalized Logistic (GLO).

- Visually assessing the goodness-of-fit for each distribution against the empirical probability distribution of the data.

The detailed output of the flood frequency analysis is provided in Appendix B. Results of the two flood frequency analyses are presented in Table 1.

Table 1 Predicted Peak Instantaneous Flows for the Dore River at the project location.

Return Period (Years)	Peak Instantaneous Flow (m^3/s)	
	Verified Data	Data including provisional record
200	186	189
100	173	177
10	129	131
2	93	91

The flood event that occurred on June 23/24, 2020 and lead to the loss of property along Dorval Road recorded a peak instantaneous flow of 171 m^3/s, which is approximately equivalent to the 70-year to 100-year flood event.

5. Hydraulic Modelling

A 2-dimensional (2D) hydraulic analysis was completed for the area of interest. We employed the Hydrologic Engineering Center - River Analysis System (HEC-RAS) v5.0.7 computational modeling software for this assignment. Developed and maintained by the US Army Corps of Engineers, the software is recognized as an industry standard and is freely available to the public.

Primary inputs for the 2-D hydraulic model included a digital elevation model (DEM) of the channel and surrounding ground, flow information developed in our flood frequency analysis, in the form of input hydrographs, and hydraulic roughness (Manning's "n") for areas in the model domain.

Using the primary inputs, the model performs a series of calculations over the model domain. Based on these calculations, the model predicts the water surface elevation (and water depth), water velocities, and direction of flow (current vector) for areas within the model domain.

5.1. LIDAR AND SITE SURVEY

Light Detection and Ranging (LiDAR) provides detailed topography of an area. LiDAR was flown for the study area in September 2020. Post-processing of the data produces a "bare earth" version of the data, which eliminates building, structures, and vegetation from the surface, resulting in only ground point elevations being reported. LiDAR does not penetrate beneath water's surface. To incorporate the Dore River channel bottom, a site survey of the channel was completed in early October 2020, during lower water conditions. A DEM was developed from the combined LiDAR and channel survey information. Channel shape was assumed for various sections of the river in the study area. The shape and channel elevations were adjusted based on the channel survey points. The result is a combined DEM that provides a basis for hydraulic modeling. Figure 13 shows a representation of the combined DEM for the study area.

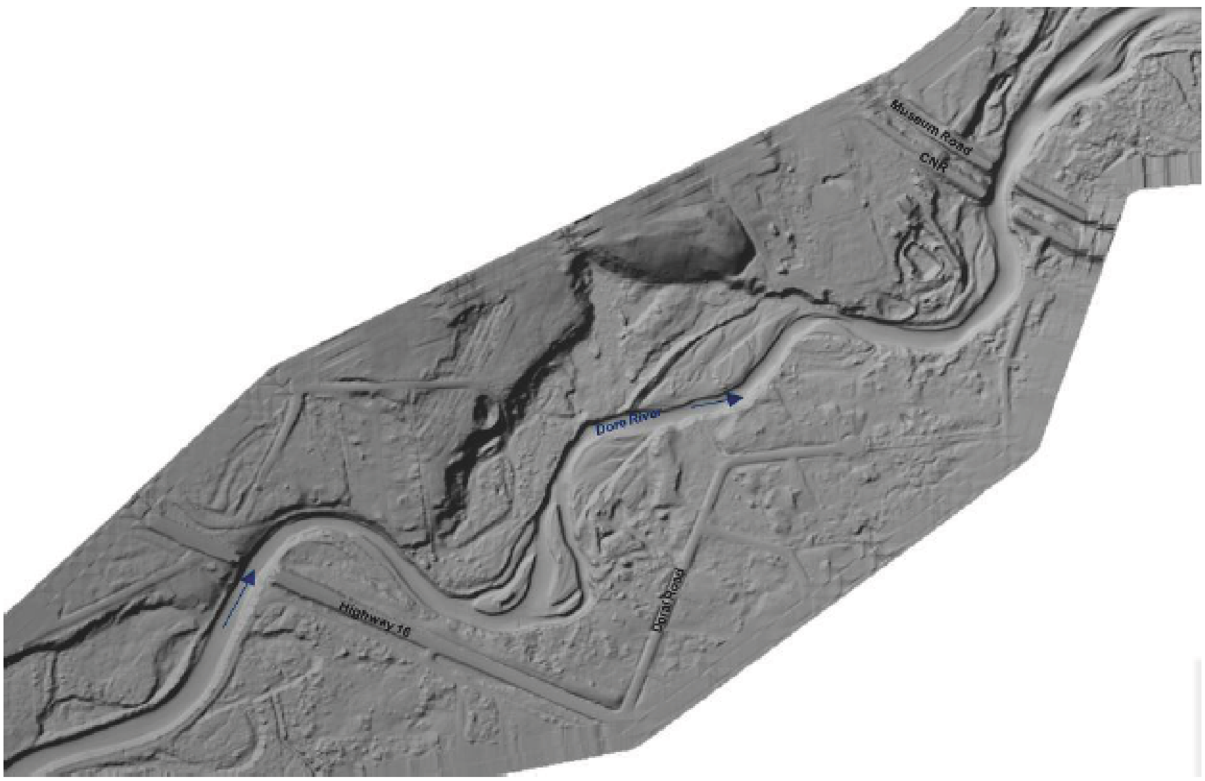


Figure 13 Digital Elevation Model (DEM). Based on LiDAR and Channel Survey (0.2m x 0.2m grid)

Primary inputs for the 2-D hydraulic model included the Light Detection and Ranging (LiDAR) of the channel and surrounding ground, flow information, in the form of input hydrographs, for the upstream extent of the model (upstream boundary condition) for the scenarios examined. Using the primary inputs, as well as other parameters such as channel/overbank roughness (Manning's "n"), the model performs a series of calculations over the model domain in order to predict the water surface elevation (and water depth), water velocities and direction of flow (current vector) for areas within the model domain.

5.2. MODEL SCENARIOS AND RESULTS

Four flow scenarios were modelled using the post flood event (current) channel geometry. The scenarios included:

- Scenario #1: 2-year flood event.
- Scenario #2: 100-year flood event.
- Scenario #3: 200-year flood event.
- Scenario #4: September 1-3, 2020 record flow (peak flow = 148 m^3/s)

The flow events recorded in June/July were not modeled, since the channel has changed significantly, and the model would not reflect the water surface elevations or water velocities experienced on those dates. The results of the hydraulic modeling are presented in Figure 14 to Figure 17. The background imagery is from 2016.

The 2-year flood event of 93 m^3/s was modelled, and the predicted water extents and velocities are shown in Figure *14*.

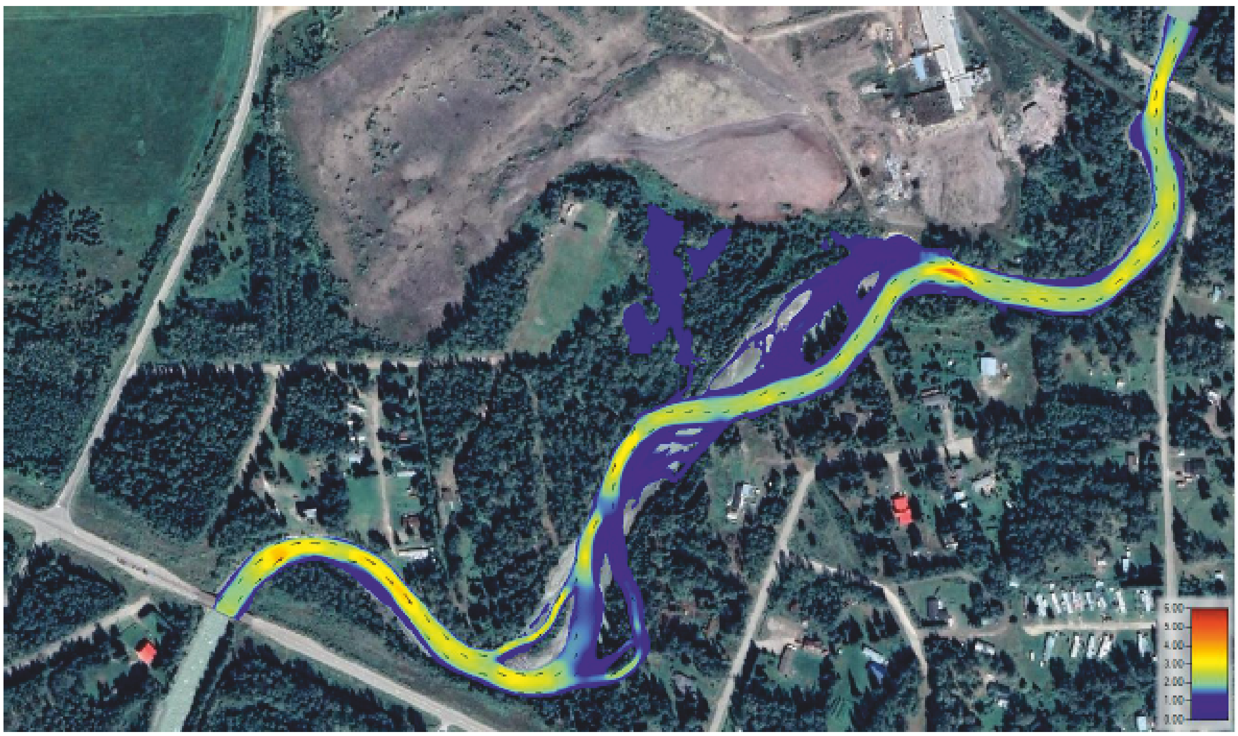


Figure 14 *Scenario #1: 2-year flood event showing predicted water velocities in m/s (colour gradient) and direction of flow (arrows)*

The 100-year flood event of 173 m³/s was modelled, and the predicted water extents and velocities are shown in Figure 15.

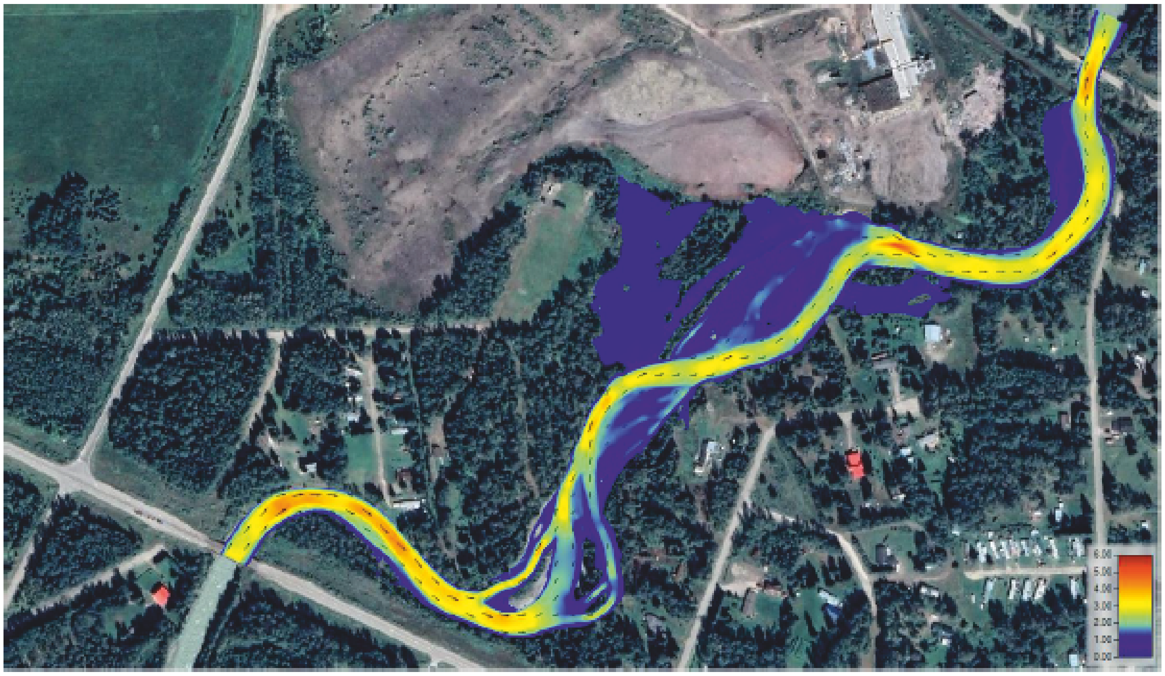


Figure 15 Scenario #2 100- year flood event showing predicted water velocities in m/s (colour gradient) and direction of flow (arrows)

The 200-year flood event of 186 m³/s was modelled, and the predicted water extents and velocities are shown in Figure 16.

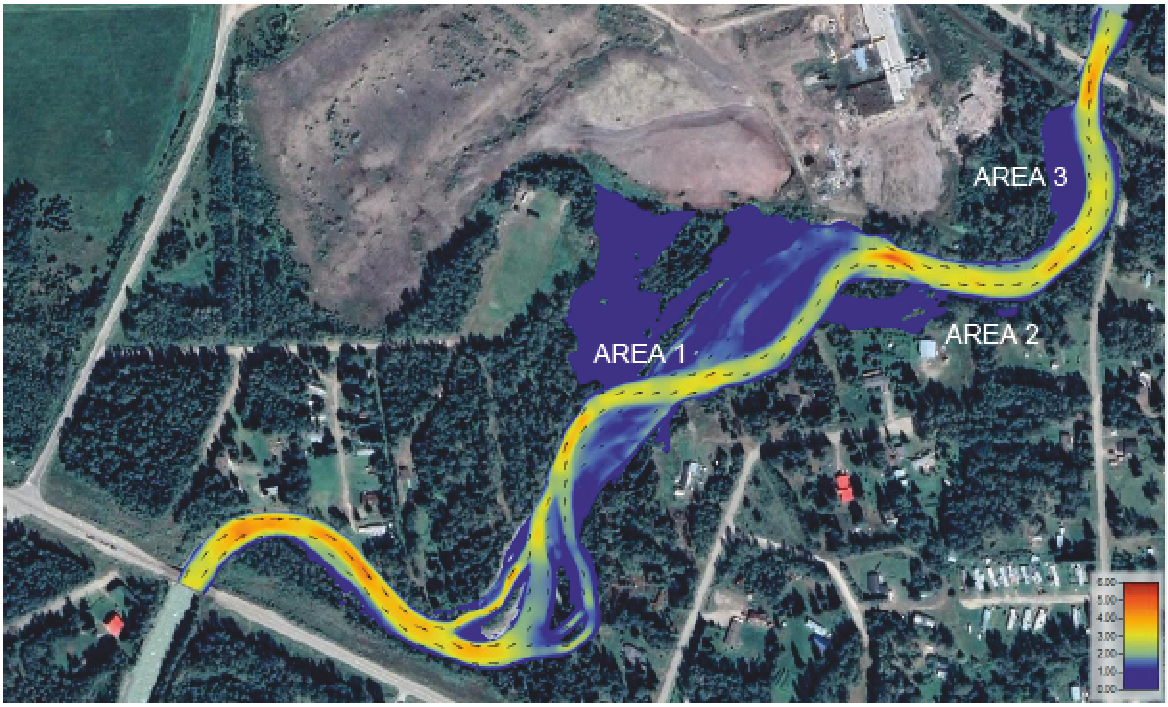


Figure 16 Scenario #3 200-year flood event showing predicted water velocities in m/s (colour gradient) and direction of flow (arrows)

5.2.1. Scenario #4: September 1-3, 2020 high water event

A large flood event occurred between September 1-3, 2020. The peak instantaneous flow recorded on the Dore River was 148 m^3/s (provisional) which is equivalent to a 25-year flood event. The predicted water extents and velocities are shown in Figure 17.

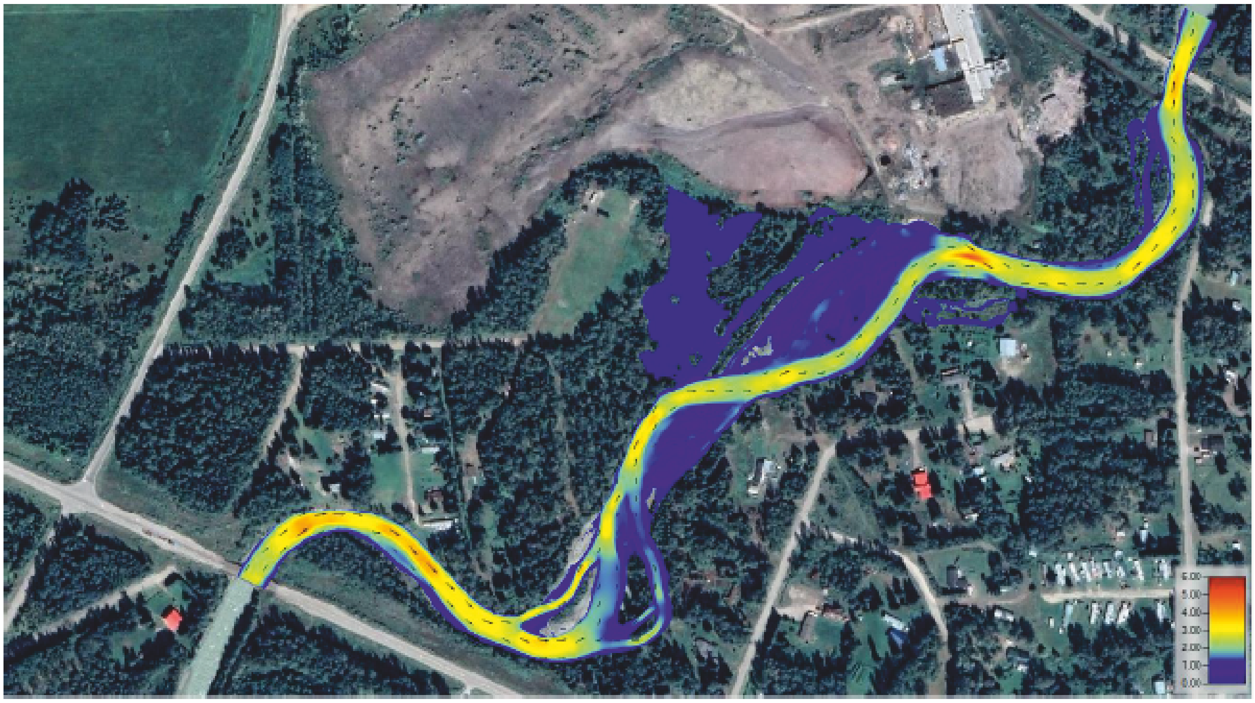


Figure 17 Scenario #4: September 1-3, 2020 high water event showing predicted water velocities in m/s (colour gradient) and direction of flow (arrows)

5.3. DISCUSSION OF MODELING RESULTS

The hydraulic model results predict the extent of inundation and associated water velocity and direction of flow under various flow scenarios. What is apparent is that even under the 200-year flow, the river is contained within its broader channel on its approach to the Dorval Road properties and through the ~90°left bend downstream of the Hwy 16 bridge. This area was subject to the most severe erosion during the June 2020 event which caused the channel to widen significantly. As a result, the hydraulic capacity of the channel (the flow it can convey within its banks) in this section has increased.

5.3.1. Overland Flooding/Inundation

The model predicts that, under extreme flows, there are three areas that are subject to overland flooding/inundation within the area of interest:

- the low-lying, forested area above the west bank of the river upstream of the mill site (Figure 16 Area 1);
- a historic flood channel located through 1655 Dorval Road (Figure 16 Area 2); and
- the area immediately upstream of the CNR and Museum Road bridges (Figure 16 Area 3). This appears to be the result of a moderate backwater effect from these crossings.

The inundation in *Area 1* occupies a low-lying depression area on the bench above the channel. The approximate water depth for the 200-year flood is 0.8 m. Flood water in *Area 2* is not unexpected since it is a historic channel of the river. The water is deeper through this section, due to the ground topography.

Water velocities are relatively low, however this channel may re-activate and convey more flow under all flow conditions. Inundation in *Area 3* appears to be the result of a backwater effect from the bridge crossings. This suggests that the hydraulic opening of the structures is slightly undersized to convey the predicted flow. The water inundates the lower bench adjacent to the channel bank.

6. Bank Erosion Assessment

BGC completed a detailed bank erosion assessment for the subject reach of the Dore River. The work included:

- a discussion of the fluvial erosion,
- an assessment of historical aerial imagery of the area of interest spanning the years 1946 to 2020;
- a discussion of previous erosion protection works completed;
- a qualitative assessment of historic bank erosion;
- model to predict the magnitude of future erosion; and
- discussions and conclusions based on the analysis.

A technical report that summarizes the work completed is included in Appendix C.

7. Geomorphologic Overview – Dore River Watershed

BGC completed a geomorphologic overview of the Dore River watershed. The overview identified geomorphic processes occurring in the watershed that could influence downstream flood hazard or channel characteristics within the AOI.

This assessment is including the BGC's report within Appendix C.

8. Conclusions and Recommendations

We provided the following recommendations related to the objective of the study, based on our assessment results.

8.1. FLOOD HAZARD

The hydraulic assessment, erosion assessment, and geomorphic assessment of the Dore provide context for the anticipated flood hazard and potential impact within the AOI.

The hydraulic modeling suggests that, given the current channel condition, overland flooding should not be a major issue, with three areas being identified as prone to experience such flooding. The largest flood hazard is within the channel itself, where the water is deepest and flowing the fastest. During high water, people should remain 10 m from the riverbank and extreme caution should be exercised when people venture closer than this distance to the river.

There remains a risk of erosion within the area of interest. With an absences of erosion protection measures, estimates range 10 m to 60 m for both banks, depending on the location within the study area. Erosion is more likely to occur on outer bends.

There is potential for landslide dams to form and fail in the upper watershed, this would result in elevated flood discharge and associated debris transport. There is also the potential for avalanche dams to form and fail. The May 1986 flood event is thought to be the result of and avalanche dam.

8.2. River Monitoring and Response

There are multiple existing resources that can be utilized to provide enhanced localized public safety notifications. The Dore River contains an active Water Survey of Canada (WSC) gauge 2 km upstream from the affected area that can provide near real time flows and water levels in the Dore River. The gauge data is accessible to the public and can be used by residents and local authorities to help monitor the site.

The B.C. River Forecast Centre is another resource that can be used in conjunction with the WSC gauge data. The River Forecast Center provides "bulletins, maps, and warning to inform the public about current and upcoming streamflow conditions".

8.2.1. WSC Gauge

The Dore River WSC gauge (Dore River near McBride 08KA001) provides real time water level and flow data for the Dore River. Anyone can access the real time gauge data via: https://wateroffice.ec.gc.ca/search/real_time_e.html. The gauge reports the current water level and corresponding flow; it does not project future flows in the river. Appendix D describes in detail how to access the real time WSC gauge data for the Dore River Gauge.

8.2.2. B.C. River Forecast Centre

The B.C. River Forecast Centre has three levels of warnings/advisories it issues. These are a High Streamflow Advisory, Flood Watch, and Flood Warning. The three warnings are described as follows:

> A ***High Streamflow Advisory*** is given when "River levels are rising or expected to rise rapidly, but that no major flooding is expected."
>
> A ***Flood Watch*** is given when "River levels are rising and will approach or may exceed bankfull. Flooding of areas adjacent to affected rivers may occur."
>
> A ***Flood Warning*** is given when "River levels have exceeded bankfull or will exceed bankfull imminently, and that flooding of areas adjacent to the rivers affected will result.

The issued advisories/warnings can be found here: http://bcrfc.env.gov.bc.ca/warnings/index.htm and the website also includes a map of the locations where warnings/advisories have been issued.

The combination of the advisory and access to near real time flow data on the Dore River can assist in helping residents and local authorities informed as to the possibility of extreme flow events.

8.2.3. Visual Observations

The real-time WSC gauge upstream of the AOI provides immediate information on flow in the Dore River. While high flows are visibly evident to local residents, the gauge provides a valuable tool to assess the potential flood hazard. We recommend that any reading above the average annual peak flow (Q2) be noted and residents should be cautious around the watercourse. If flow increase above that flow, exceeding caution should be exercised.

Coupled with weather forecasts and river forecasting center advisories, the District can issue appropriate warnings to residents. If residents notice events such as a build up of debris in the channel during a flood event they can call the EMBC number at 1-800-663-3456 and report the incident. EMBC will then contact the RDFFG.

8.3. FLOOD PROTECTION MEASURES

The 2020 event was the result of flooding which caused significant bank erosion. The threat posed to the properties was due to land loss, and not inundation of structures from flooding.

8.3.1. Temporary Measures

Temporary flood mitigation measures generally involve the deployment of portable diking measures in areas known to be prone to overland flooding. These would include sandbagging, "aqua-dams" (water filled bladders), water filled HDPE barriers, etc. In the area of interest, overland flooding/inundation appears to be restricted to low-lying, wet, forested areas (Area 1), historic channels (Area 2), and areas subject to backwater due to bridges immediately downstream (Area 3). Deployment of temporary flood mitigation measures at these locations would not provide significant benefit and are not recommended.

8.3.2. Permanent Measures

Permanent flood protection measures in the form of diking (dikes or flood walls) would not provide significant benefit, since overland flooding is not a large threat to property or infrastructure. Continued erosion, especially on outer bends of the river, remains a possibility.

An effective permanent bank erosion protection measure is to armour the riverbank with riprap. Figure E-1 in Appendix E shows the proposed riprap extents. Any bank protection measures should maintain the wider river geometry. This will allow the river to follow its natural tendency to meander within its active floodplain.

The riprap would be required to be installed along 1,200 m of the riverbank. An estimate of the riprap size is Class 250 kg installed at a thickness of 1 m. Once the riprap is installed, bank stability will also benefit from revegetation.

We note that these are conceptual level design estimates and engineering design of any bank erosion mitigation measure must be completed.

8.4. DECISION SUPPORT TO LOCAL GOVERNMENT EMERGENCY RESPONSE PLAN FOR IMMEDIATE RESPONSE AND PUBLIC SAFETY ALERTING TRIGGERS

As stated in section 7.2.3, recorded flows provided a good indication of flood hazard. Under high flow scenarios, the modelling shows access and egress to the site will not be compromised due to clear water flooding.

8.5. TEMPORARY DEBRIS MANAGEMENT SITES

Extreme flood events are capable of transporting and depositing large quantities of debris. Removal and disposal of debris is sometimes required. The RDFFG has their Legrand Demolition and Construction Waste Landfill which is located near McBride and will be able to provide an area to stage and separate any additional construction and demolition waste, as per the RDFFG's Regional Solid Waste Plan.

9. Closing

The assessment has been prepared by McElhanney for the benefit of the RDFFG. The information and data contained herein represent McElhanney's best professional judgement in light of the knowledge and information available to McElhanney at the time of preparation.

McElhanney denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this document or any of its contents without the express written consent of McElhanney and the RDFFG.

We thank you for the opportunity to work on this project. Please do not hesitate to contact us if you have any questions.

Yours truly,

McElhanney Ltd.

Prepared by:

Lucy Swank, EIT

Hydrotechnical Project Engineer

Reviewed by:

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA D. A. JOHNSTON # 36019

2021-03-11

Doug Johnston, P.Eng.

Senior Hydrotechnical Engineer

10. References

BC Ministry of Transportation and Infrastructure (MoTI). 2019. Supplement to TAC Geometric Design Guide Hydraulics Chapter.

APPENDIX A –DORE RIVER FLOODING ASSESSMENT TECHNICAL MEMO (JULY 3, 2020)

TECHNICAL MEMO

To	From
Regional District of Fraser-Fort George (RDFFG)	Lucy Swank, Hydrotechnical EIT McElhanney Prince George
Re	**Date**
Dore River Flooding Assessment	July 3, 2020

The Dore River, located west of McBride, BC, experienced a 1 in 100-year flood event (preliminary estimates) on June 23/24, 2020. The flood caused multiple property owners along Dorval Road to lose significant portions of their property to erosion. On June 30, 2020 Environment Canada released a special weather statement for central and northern BC. A storm moving west from Alberta would cause prolonged, and heavy rainfall throughout the region. The heavy rainfall has the potential to trigger flooding within the Upper Fraser Watershed, including the Dore River. The potential for additional flooding led the Regional District of Fraser-Fort George (RDFFG) to request McElhanney to assess areas that could be further damaged by flooding from the Dore River.

The purpose of this memo is to summarize the observations made during the site visit, provide comments on water flows and the potential for immediate impacts (within the next few days) to the area. It does not include design recommendations or long-term impacts.

1. Site Visit

The site visit was attended by Lucy Swank, a hydrotechnical engineer from McElhanney, and Dean Schneider, a RDFFG representative. The visit occurred between 9:30 am and 3:00 pm on July 1st, 2020. On site at the same time was the contractor hired to remove the debris jam (Photo 1) that had formed during the June 23/24 flood event. The site visit focussed on the Dore River from the property at 905 Dorval Road north to 1655 Dorval Road. The properties most affected were 905, 1005 (Photos 2 and 3), 1475 (Photo 4), and 1655 Dorval Road (Photo 5). These properties had experienced the greatest property loss. There is concern regarding the vulnerability of the community pumphouse. It was noted there is a vegetated berm between the pumphouse and the river. The thalweg (main channel) of the river is located away from the adjacent river bank with multiple gravel bars in between the bank and the thalweg at this location (Photo 6).

At the time of the site visit, the flow in the river was approximate 65 m^3/s, as measured and reported at the Water Survey of Canada (WSC) gauge located 2800 m upstream of the site. This represents approximately 65% of the average annual peak flow (the 2-year flood event) in the watercourse. Given the water conditions at the time of the site visit, there were no areas identified as being in imminent danger of significant erosion.

We note that at the time of preparing this memo, the flow in the Dore River almost doubled over the following night, with a peak of 113 m^3/s occurring at 2:35 am July 2nd.

Channel erosion that resulted from the June 23rd event has significantly widened the channel in most places. Increases in flow from the current level will have less dramatic increases in water surface elevation since the water will occupy the entire river width available to it.

The thalweg in the upstream portion of the reach appears to be immediately adjacent to the right bank. It transitions to the left side of the channel in the middle of the reach. Figure 1 provides a sketch of the estimated location (blue line) of the current thalweg. The rate of erosion should decrease as flow decreases. We recommend stakes and/or paint markings be instituted along the bank to monitor the locations and rates of erosion. It would be advantageous for the erosion monitoring to be conducted by property owners as they will be able to provide more frequent monitoring of the areas of concern. The approximate location of the right bank at the time of the site visit is shown in Figure 1. It is expected that the channel to the left of the log jam will remain a secondary channel. It is uncertain if the log jam will re-establish at its current location given the large shift in the thalweg. Site photographs along the length of the river reach are presented in Photos 1 through Photo 6.

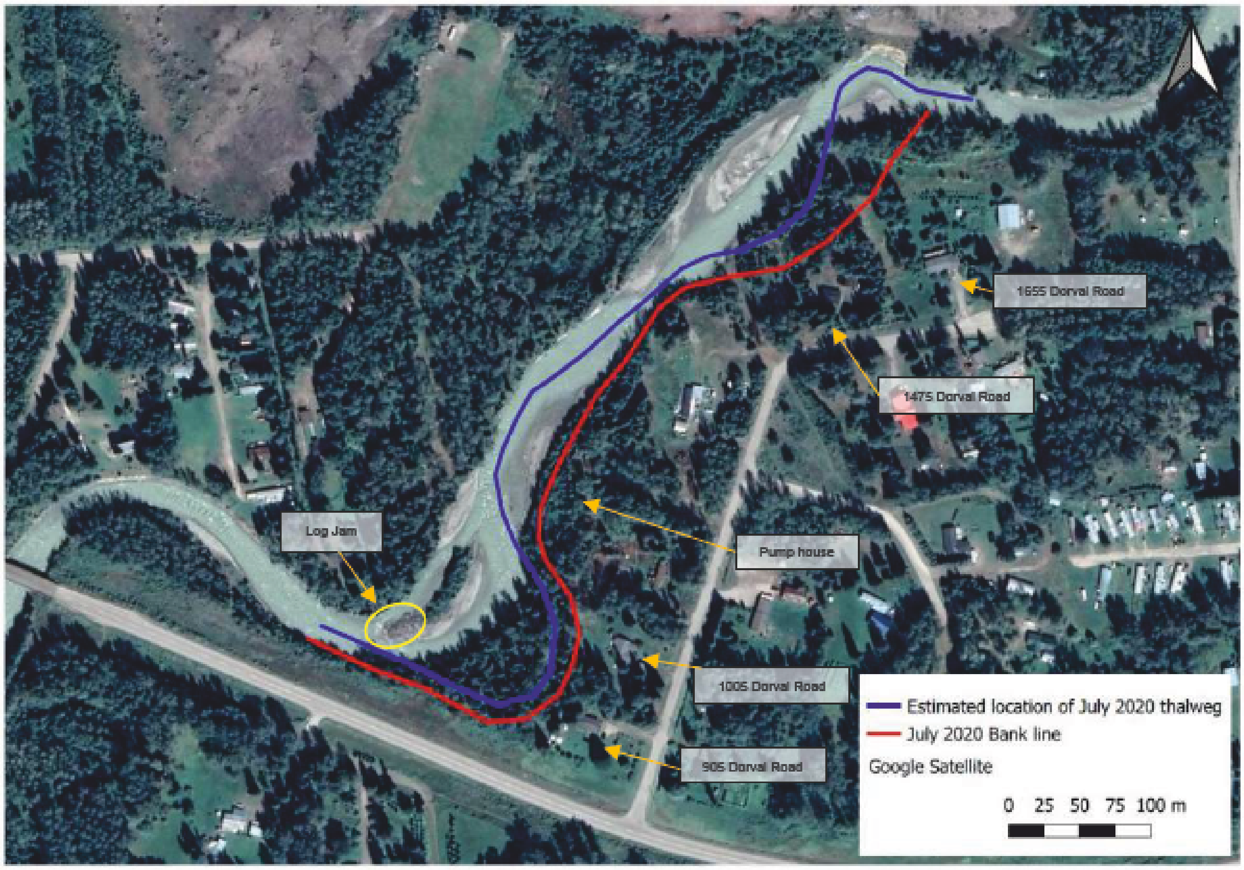


Figure 1: Overview map of area showing estimated location of the new right bank (red) and estimated location of the river thalweg (blue)

Photo 1: Excavator removing debris jam

Photo 2: Looking upstream from the edge of the property located at 1005 Dorval Road

Photo 3: Looking downstream from the edge of the property located at 1005 Dorval Road. Property line use to extend out the gravel bar now in center of channel.

Photo 4: Looking upstream from edge of 1475 Dorval Road. Property previously extended 50+ feet into the river.

Photo 5: Berm constructed across low area by homeowner at 1655 Dorval Road

Photo 6: River channel and gravel bars in front of berm protecting community pumphouse

The assessment has been prepared by McElhanney Ltd. (McElhanney) for the benefit of the Regional District of Fraser-Fort George. The information and data contained herein represent McElhanney's best professional judgement in light of the knowledge and information available to McElhanney's at the time of preparation.

McElhanney Ltd. denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this document or any of its contents without the express written consent of McElhanney or the Regional District of Fraser-Fort George.

We thank you for the opportunity to work on this project. Please do not hesitate to contact us if you have any questions.

Yours truly,

McElhanney Ltd.

Lucy Swank

Lucy Swank, EIT
Hydrotechnical Project Engineer

Doug Johnston P.Eng
Senior Hydrotechnical Engineer

APPENDIX B – DORE RIVER FLOOD FREQUENCY ANALYSIS

Flood Frequency Analysis

08KA001	DORE RIVER NEAR MCBRIDE				Watershed Area:	Published:	409	
						Measured:	408.4	

INSTANTANEOUS — Flow (m^3/s)

Prob of Non-exceedance	Return Period	GEV	3-Parm Log-Normal	Log Pearson III	Wakeby	Generalized Logistic	Weibull	Gumbel
0.5	2	93.02	93.02	92.85	93.07	93.39	92.91	92.98
0.8	5	114.53	114.69	114.66	115.81	112.98	115.82	114.49
0.9	10	128.73	128.79	129.25	129.98	126.75	129.76	128.73
0.95	20	142.32	142.37	143.41	142.45	141.2	142.13	142.38
0.96	25	146.63	146.4	147.95	146.19	146.31	145.87	146.72
0.98	50	159.88	159.39	162.51	156.95	162.15	156.89	160.06
0.99	100	173	172.3	176.49	166.54	180.37	167.17	173.33
0.995	200	186.05	185.24	191.22	175.1	200.5	176.87	186.53
0.998	500	203.23	202.49	211.36	185.01	230.88	188.96	203.92
0.999	1000	216.19	215.71	227.2	191.57	257.14	197.65	217.08

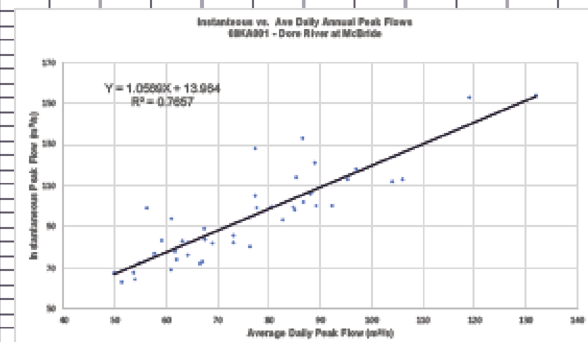
AVERAGE DAILY — Flow (m^3/s)

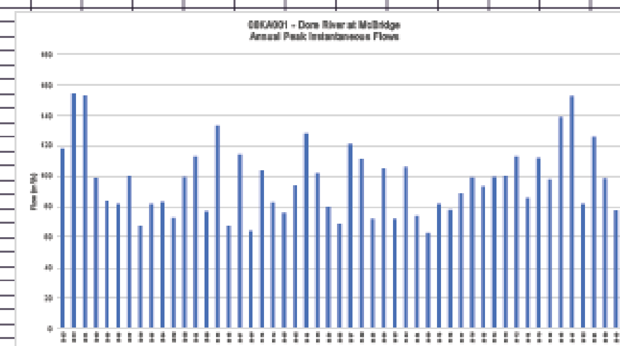
Prob of Non-exceedance	Return Period	GEV	3-Parm Log-Normal	Log Pearson III	Wakeby	Generalized Logistic	Weibull	Gumbel
0.5	2	75.0	74.9	74.8	75.2	75.3	74.8	75.1
0.8	5	93.3	93.5	93.5	94.3	92.0	94.5	93.5
0.9	10	105.6	105.7	106.1	105.4	103.9	106.6	105.6
0.95	20	117.5	117.5	118.5	116.0	116.5	117.5	117.3
0.96	25	121.4	121.2	122.5	119.4	120.8	120.8	121.0
0.98	50	133.2	132.7	135.1	130.3	135.1	130.5	132.4
0.99	100	145.0	144.2	147.9	141.9	151.1	139.6	143.7
0.995	200	156.9	155.8	161.2	154.2	169.2	148.2	154.9
0.998	500	172.8	171.3	179.5	171.9	196.6	159.0	169.8
0.999	1000	185.0	183.3	194.0	186.4	220.5	166.8	181.0

171	171	148.6
82.2	82.2	64.5
52.7	52.7	36.6
45.1	45.1	29.4
48.2	48.2	32.4
60.5	60.5	44.0

ANNUAL RECORDS 0.4

Station Number	Year	Annual Ave Daily	Instantaneous	Inst. Used	Emp Prob	Rank	Count	I/D ratio
08KA001	2013	97	118	118	#REF!	9	51	
08KA001	2012	132	154	154	#REF!	1		1.22
08KA001	2011	119	153	153	#REF!	2		1.17
08KA001	2010	56.2	98.9	98.9	#REF!	24		1.29
08KA001	2009	67.5	83.7	83.7	#REF!	31		1.76
08KA001	2008	64.2	81.9	81.9	#REF!	36		1.24
08KA001	2007	92.3	100	100	#REF!	19		1.28
08KA001	2006	53.6	67.5	67.5	#REF!	48		1.08
08KA001	2005	69	81.8	81.8	#REF!	37		1.26
08KA001	2004	59.1	83.2	83.2	#REF!	32		1.19
08KA001	2003	67	72.8	72.8	#REF!	44		1.41
08KA001	2002	80.5	99.6	99.6	#REF!	21		1.09
08KA001	2001	93.3	113	113	#REF!	11		1.24
08KA001	2000	57.7	76.8	76.8	#REF!	41		1.19
08KA001	1999	86.5	133	133	#REF!	5		1.33
08KA001	1998	49.8	67.3	67.3	#REF!	49		1.54
08KA001	1997	85.3	114	114	#REF!	10		1.35
08KA001	1996	53.9	64.2	64.2	#REF!	50		1.34
08KA001	1995	85		103.82	#REF!	17		1.19
08KA001	1994	63.1	82.9	82.9	#REF!	33		
08KA001	1993	64.2	76	76	#REF!	42		1.31
08KA001	1992	61	93.8	93.8	#REF!	27		1.18
08KA001	1991	77.3	128	128	#REF!	6		1.54
08KA001	1990	86.7	102	102	#REF!	18		1.66
08KA001	1989	76.3	80	80	#REF!	38		
08KA001	1988	60.9	68.8	68.8	#REF!	47		1.05
08KA001	1987	88.9	121	121	#REF!	8		1.13
08KA001	1986	92		111.22	#REF!	14		1.36
08KA001	1985	66.6	71.9	71.9	#REF!	46		
08KA001	1984	77.3	105	105	#REF!	16		1.08
08KA001	1983	54.8	72.3	72.3	#REF!	45		1.36
08KA001	1982	88.1	106	106	#REF!	15		1.32
08KA001	1981	62	73.8	73.8	#REF!	43		1.20
08KA001	1980	51.3	62.8	62.8	#REF!	51		1.19
08KA001	1979	73.1	82.1	82.1	#REF!	34		1.22
08KA001	1978	61.7	77.9	77.9	#REF!	39		1.12
08KA001	1977	67.4	88.9	88.9	#REF!	29		1.26
08KA001	1976	77.6	99.1	99.1	#REF!	23		1.32
08KA001	1975	82.7	93.2	93.2	#REF!	26		1.28
08KA001	1974	84.7	99.4	99.4	#REF!	22		1.13
08KA001	1973	89.2	100	100	#REF!	19		1.17
08KA001	1972	106	113	113	#REF!	11		1.12
08KA001	1971	73.1	85.5	85.5	#REF!	30		1.07
08KA001	1970	104	112	112	#REF!	13		1.17
08KA001	1969	85	98	98	#REF!	26		1.06
08KA001	1968	118		138.69	#REF!	4		1.15
08KA001	1967	131		152.43	#REF!	3		
08KA001	1952	64.3		81.94	#REF!	35		
08KA001	1951	106		126.01	#REF!	7		
08KA001	1950	79.9		98.43	#REF!	25		
08KA001	1949	60		77.4	#REF!	40		
					-	-		
					-	-		
					-	-		
					-	-		
					-	-		
					-	-		
					-	-		
					-	-		





08KA001 DORE RIVER NEAR MCBRIDE INCLUDING 2014-2020 PROVISIONAL GAUGE DATA

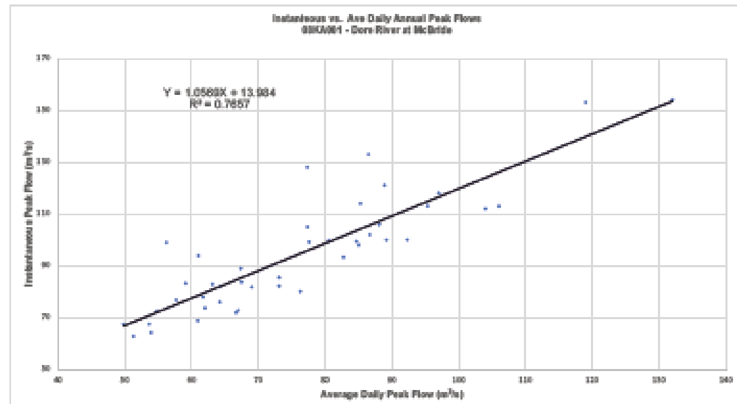
Watershed Area: Published: 409
Measured: 408.4

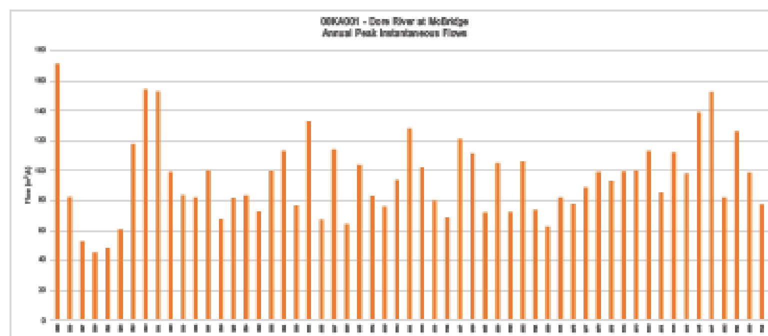
INSTANTANEOUS		Flow (m^3/s)						
Prob of Non-exceedence	Return Period	GEV	3-Parm Log-Normal	Log Pearson III	Wakeby	Generalized Logistic	Weibull	Gumbel
0.5	2	91.0	91.1	91.3	90.4	91.4	91.0	90.2
0.8	5	115.7	115.8	116.0	115.7	113.8	116.9	115.0
0.9	10	131.3	131.2	131.4	132.4	129.1	132.1	131.4
0.95	20	145.8	145.5	145.7	147.2	144.8	145.3	147.1
0.96	25	150.3	150.0	150.1	151.6	150.0	149.3	152.1
0.98	50	163.7	163.5	163.4	164.3	167.1	160.9	167.5
0.99	100	176.6	176.7	176.4	175.6	185.7	171.5	182.7
0.995	200	189.0	189.7	189.2	185.6	206.0	181.5	197.9
0.998	500	204.8	206.7	205.9	197.1	235.9	193.8	218.0
0.999	1000	216.2	219.6	218.5	204.8	261.2	202.6	233.1

AVERAGE DAILY		Flow (m^3/s)						
Prob of Non-exceedence	Return Period	GEV	3-Parm Log-Normal	Log Pearson III	Wakeby	Generalized Logistic	Weibull	Gumbel
0.5	2	73.3	73.3	73.8	72.8	70.6	73.3	72.5
0.8	5	95.0	95.0	95.5	94.1	93.3	96.0	94.3
0.9	10	108.6	108.5	108.5	108.8	106.7	109.2	108.7
0.95	20	121.1	120.8	120.1	122.5	120.2	120.7	122.5
0.96	25	124.9	124.7	123.6	126.7	124.8	124.1	126.9
0.98	50	136.4	136.3	134.1	139.2	139.5	134.1	140.5
0.99	100	147.4	147.6	144.0	150.7	155.4	143.2	153.9
0.995	200	157.8	158.7	153.4	161.5	172.8	151.8	167.3
0.998	500	171.0	173.2	165.3	174.6	198.2	162.3	184.9
0.999	1000	180.4	184.1	174.0	183.6	219.5	169.9	198.3

0.4

ANNUAL RECORDS								
Station Number	Year	Annual Ave Daily	Instantaneous	Inst. Used	Emp Prob	Rank	Count	I/D ratio
	2020	148.6		171	#REF!	1	57	0.00
	2019	64.5		82.2	#REF!	35		0.00
	2017	36.6		53.7	#REF!	55		0.00
	2016	29.4		45.1	#REF!	57		0.00
	2015	32.4		48.2	#REF!	56		0.00
	2014	44.0		60.5	#REF!	54		0.00
08KA001	2013	97	118	118	#REF!	10		1.22
08KA001	2012	132	154	154	#REF!	2		1.17
08KA001	2011	119	153	153	#REF!	3		1.29
08KA001	2010	56.2	98.9	98.9	#REF!	25		1.76
08KA001	2009	67.5	83.7	83.7	#REF!	32		1.24
08KA001	2008	64.2	81.9	81.9	#REF!	38		1.28
08KA001	2007	92.3	100	100	#REF!	20		1.08
08KA001	2006	53.6	67.5	67.5	#REF!	50		1.26
08KA001	2005	69	81.8	81.8	#REF!	39		1.19
08KA001	2004	59.1	83.2	83.2	#REF!	33		1.41
08KA001	2003	67	72.8	72.8	#REF!	46		1.09
08KA001	2002	80.5	99.6	99.6	#REF!	22		1.24
08KA001	2001	95.3	113	113	#REF!	12		1.19
08KA001	2000	57.7	76.8	76.8	#REF!	43		1.33
08KA001	1999	86.5	133	133	#REF!	6		1.54
08KA001	1998	49.8	67.3	67.3	#REF!	51		1.35
08KA001	1997	85.3	114	114	#REF!	11		1.34
08KA001	1996	53.9	64.2	64.2	#REF!	52		1.19
08KA001	1995	85		103.82	#REF!	18		
08KA001	1994	63.1	82.9	82.9	#REF!	34		1.31
08KA001	1993	64.2	76	76	#REF!	44		1.18
08KA001	1992	61	93.8	93.8	#REF!	28		1.54
08KA001	1991	77.3	128	128	#REF!	7		1.66
08KA001	1990	86.7	102	102	#REF!	19		
08KA001	1989	76.3	80	80	#REF!	40		1.05
08KA001	1988	60.9	68.8	68.8	#REF!	49		1.13
08KA001	1987	88.9	121	121	#REF!	9		1.36
08KA001	1986	92		111.22	#REF!	15		
08KA001	1985	66.6	71.9	71.9	#REF!	48		1.08
08KA001	1984	77.3	105	105	#REF!	17		1.36
08KA001	1983	54.8	72.3	72.3	#REF!	47		1.32
08KA001	1982	88.1	106	106	#REF!	16		1.20
08KA001	1981	62	73.8	73.8	#REF!	45		1.19
08KA001	1980	51.3	62.8	62.8	#REF!	53		1.22
08KA001	1979	70.1	82.1	82.1	#REF!	36		1.12
08KA001	1978	61.7	77.9	77.9	#REF!	41		1.26
08KA001	1977	67.4	88.9	88.9	#REF!	30		1.32
08KA001	1976	77.6	99.1	99.1	#REF!	24		1.28
08KA001	1975	82.7	99.2	99.2	#REF!	29		1.19
08KA001	1974	84.7	99.4	99.4	#REF!	23		1.17
08KA001	1973	89.2	100	100	#REF!	20		1.12
08KA001	1972	106	113	113	#REF!	12		1.07
08KA001	1971	73.1	85.5	85.5	#REF!	31		1.17
08KA001	1970	104	112	112	#REF!	14		1.08
08KA001	1969	85	98	98	#REF!	27		1.15
08KA001	1968	118		138.69	#REF!	5		
08KA001	1967	131		152.43	#REF!	4		
08KA001	1952	64.3		81.94	#REF!	37		
08KA001	1951	106		126.01	#REF!	8		
08KA001	1950	79.9		98.43	#REF!	26		
08KA001	1949	60		77.4	#REF!	42		
				-		-		
				-		-		
				-		-		
				-		-		
				-		-		





				Est Return Period (years)			
Year	Inst. Peak	GEV	LN3	WAKEBY	Gen. Logistic	Weibull	Gumbel
2020	171	73.53	74.07	74.63	58.14	96.15	58.82
2019	83.2	1.56	1.56	1.54	1.52	1.59	1.58
2017	52.7	1.03	1.03	1.04	1.04	1.02	1.02
2016	45.1	1.01	1.01	1.01	1.02	1	1
2015	48.2	1.01	1.01	1.02	1.02	1	1.01
2014	60.5	1.08	1.08	1.09	1.08	1.08	1.07
2013	118	5.51	5.51	5.48	6.04	5.24	5.66
2012	154	30.21	30.67	28.33	29.59	32.89	27.25
2011	153	28.74	29.15	26.88	28.33	31.06	26.04
2010	98.9	2.6	2.59	2.68	2.64	2.55	2.68
2009	83.7	1.62	1.62	1.61	1.58	1.65	1.65
2008	81.9	1.55	1.55	1.53	1.51	1.58	1.57
2007	100	2.7	2.69	2.78	2.75	2.64	2.79
2006	67.5	1.17	1.17	1.16	1.16	1.19	1.16
2005	81.8	1.55	1.55	1.52	1.5	1.57	1.56
2004	83.2	1.6	1.6	1.59	1.56	1.63	1.62
2003	72.8	1.27	1.28	1.24	1.25	1.3	1.27
2002	99.6	2.66	2.65	2.74	2.71	2.61	2.75
2001	113	4.46	4.46	4.5	4.81	4.26	4.61
2000	76.8	1.38	1.38	1.34	1.34	1.41	1.38
1999	133	10.81	10.88	10.28	11.92	10.46	10.72
1998	67.3	1.17	1.17	1.15	1.15	1.18	1.16
1997	114	4.65	4.64	4.68	5.06	4.44	4.8
1996	64.2	1.12	1.12	1.12	1.12	1.13	1.11
1995	109.83	3.11	3.1	3.19	3.22	3.02	3.22
1994	82.9	1.59	1.59	1.57	1.55	1.61	1.61
1993	76	1.35	1.36	1.32	1.32	1.38	1.36
1992	96.8	2.18	2.18	2.24	2.17	2.17	2.25
1991	120	8.58	8.61	8.27	9.51	8.2	8.64
1990	102	2.9	2.9	2.99	2.99	2.83	3.01
1989	80	1.48	1.48	1.45	1.44	1.51	1.49
1988	68.8	1.19	1.19	1.17	1.18	1.21	1.19
1987	121	6.27	6.28	6.18	6.92	5.96	6.41
1986	111.22	4.15	4.14	4.21	4.45	3.97	4.29
1985	71.9	1.25	1.26	1.22	1.23	1.28	1.25
1984	105	3.25	3.24	3.33	3.39	3.15	3.36
1983	72.3	1.26	1.26	1.23	1.24	1.29	1.26
1982	106	3.37	3.37	3.46	3.54	3.26	3.5
1981	73.8	1.3	1.3	1.26	1.27	1.32	1.3
1980	63.8	1.11	1.11	1.11	1.1	1.11	1.1
1979	83.1	1.56	1.56	1.54	1.51	1.58	1.58
1978	77.9	1.41	1.41	1.37	1.37	1.44	1.42
1977	88.9	1.88	1.87	1.9	1.86	1.89	1.92
1976	99.1	2.62	2.61	2.7	2.66	2.57	2.7
1975	93.2	2.14	2.14	2.2	2.13	2.13	2.2
1974	99.4	2.64	2.64	2.73	2.69	2.59	2.73
1973	100	2.7	2.69	2.78	2.75	2.64	2.79
1972	113	4.46	4.46	4.5	4.81	4.26	4.61
1971	85.5	1.7	1.7	1.71	1.66	1.72	1.73
1970	112	4.28	4.28	4.33	4.6	4.1	4.43
1969	98	2.52	2.51	2.59	2.55	2.48	2.6
1968	130.69	14.16	14.31	13.3	15.36	13.99	13.76
1967	152.43	27.93	28.33	26.11	27.7	30.03	25.38
1952	81.94	1.55	1.55	1.53	1.51	1.58	1.57
1951	126.01	7.94	7.86	7.6	8.7	7.47	7.83
1950	98.43	2.55	2.55	2.63	2.59	2.51	2.64
1949	77.4	1.4	1.4	1.36	1.36	1.42	1.4

APPENDIX C – BGC'S DORE RIVER SUSTAINED EMERGENCY RESPONSE - GEOMORPHIC ASSESSMENT

BGC

MCELHANNEY LTD.

Dore River Sustained Emergency Response – Geomorphic Assessment

Final
March 10, 2021

BGC Document No.:
1572006

Prepared by BGC Engineering Inc. for:
McElhanney

TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS
DRAFT	January 7, 2021		Original issue
FINAL	March 10, 2021		Sealed report issued

LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of McElhanney Ltd. and the Regional District of Fraser-Fort George (RDFFG). The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

As a mutual protection to our client, the public, and ourselves, all documents and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding our documents and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval. A record copy of this document is on file at BGC. That copy takes precedence over any other copy or reproduction of this document.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF DRAWINGS

1. INTRODUCTION

The Regional District of Fraser-Fort George (RDFFG, the District) issued an emergency scope of work request to complete a sustained emergency assessment of Dore River (emergency assessment), located about 4 km northwest of McBride, British Columbia (RDFFG, 2020). Drawing 01 provides a location map of the watershed. The request followed notification to the District by the Water Stewardship Division of the BC Ministry of Environment (WSD) about flood and erosion hazards to people and development within an area of interest (AOI) shown in yellow on Drawing 02.

McElhanney Ltd. (McElhanney) was retained by RDFFG to complete the emergency scope of work, which included a hydrogeomorphic hazard assessment within the AOI. McElhanney subcontracted BGC Engineering Inc. (BGC) to complete a portion of the work under the terms of a contract between BGC and McElhanney dated October 16, 2020. Specifically, McElhanney requested that BGC provide assessments in the following two areas, as input to a flood assessment and subsequent mitigation planning within the AOI:

- A summary of upper Dore River watershed geomorphology as it relates to potential downstream flood concerns within the AOI.
- An assessment of bank erosion within the AOI.

Sections 2 and 3 provide a description of BGC's methods and results for the two tasks noted above. They have been written for insertion into a larger report to be prepared by McElhanney for the RDFFG. The watershed assessment was based on desktop analyses of available remote-sensed imagery (satellite imagery and air photos) and information from BGC's hydrological analysis software, River Network Tools™[1]. The bank erosion assessment involved a desktop analysis of available imagery, as well as the use of a predictive bank erosion model.

[1] RNT is a web-based application developed by BGC for analysing hydrotechnical geohazards associated with rivers and streams.

2. WATERSHED GEOMORPHOLOGIC OVERVIEW

This section provides a qualitative overview of Dore River watershed upstream of development (i.e., upstream of Water Survey of Canada (WSC) stream gauge 08KA001, about 2 km upstream of the AOI). The objective of the assessment is to identify, at an overview level of detail, geomorphic processes occurring within the watershed that could influence downstream flood hazard or channel characteristics within the AOI.

BGC considered the following information sources in the desktop-based assessment[2]:

- Satellite imagery as visible via Google Earth
- Historical air photos as listed in Appendix A
- Geological information
- Watershed morphometrics (area, stream length) obtained via BGC's hydrological analysis software, River Network Tools™.

The glaciated watershed of Dore River encompasses about 419 km^2 and contains several named and unnamed tributaries (Drawing 01). It has a total watershed relief of about 2254 m that extends from 710 m above sea level at the Fraser River confluence to 2,964 m at Chevron Peak.

Bedrock geology in the watershed consists of an assemblage of old (> 500 million years) sedimentary and low-grade metamorphic rocks, including limestone, dolostone, mudstone, siltstone and phyllite, rocks that are often associated with widespread deep-seated landslides due to their low rock mass and frictional strength, heavy weathering and disintegration into clay-rich materials that promote landsliding (Province of BC, 2014). Logged, forested lower valley slopes are blanketed by till mostly covered by coalescing steep creek fans that provide sediment to the main channels. Upper slopes contain steep, exposed bedrock partially covered in thin colluvium, with rapidly retreating small cirque glaciers present on dominantly north-facing slopes at the highest elevations.

Geohazards identified within the watershed include snow avalanches, clear-water floods, steep creek processes (debris flows, debris floods), rock slides and rock fall on steep, upper valley slopes. BGC also identified landforms interpreted as deep-seated slope movement, which are described further below.

Drawing 01 displays stream channels classified by predicted geomorphic process type (debris flow, debris flood, or flood) according to statistical methods described by Holm, Jakob, and Scordo (2016), who related stream process type to class limits for Melton Ratio[3] and maximum stream length upstream of a given stream segment (Table 2-1). While the study AOI is downstream of the runout zone for debris flows or debris floods in the upper watershed, such events from tributaries are the dominant sediment source to Dore River. Downstream implications to the AOI include effects of sediment supply on channel characteristics, including channel aggradation, migration, and bank erosion. BGC notes that statistical classification of stream process type has

[2] No fieldwork was completed.
[3] Watershed relief divided by the square root of watershed area.

limitations described by Holm et al. (2019) and does not indicate hazard frequency or magnitude; it is provided here as context for hazard types occurring in the watershed.

Table 2-1. Class boundaries using total stream network length for watersheds without a mapped fan.

Process	Melton Ratio	Stream Length (km)
Floods	< 0.2	all
Debris floods	0.2 to 0.5	all
	> 0.5	> 3
Debris flows	> 0.5	≤ 3

Drawing 01 also indicates scarps (red outlines) at the crest of slope movement landforms. The landforms indicated on Drawing 01 are interpreted as being large enough (on the order of many tens to hundreds of thousands of cubic metres) to potentially cause blockage of a main channel, with implications for downstream flooding. There is also evidence of past landslides having impounded Dore River in the past. Figure 2-1 shows one example on the south side of Upper Boreal Creek, where slope movement has pushed the channel toward the north side of the valley bottom. Subject to field confirmation, BGC interprets that phyllitic texture rock is contributing to the relative abundance of large-scale slope movement within the watershed.

Estimation of the likelihood, characteristics, and magnitude of landslide-dam outbreak floods requires the assessment of a chain of events including landslide occurrence, the formation and failure of the dam, and the characteristics of downstream flood or debris flood discharge. Such assessment is outside the scope of this study. BGC examined air photos from 1947 to 2006 to search for landslides occurring and blocking main stem channels but did not identify surface evidence (e.g., vegetation scars or fresh channel deposits) with obvious relation to recent (since 1947) landslide dam impoundments or outbreak floods. This indicates that the historic return period of landslide impoundments is likely greater than 100 years.

Eugene Runtz of Runtz Forest Management Ltd. (October 23, 2020) provides a detailed account of a flood event occurring on May 26, 1986. Mr. Runtz described the event as follows:

> The flooding occurred on the late afternoon of May 26. The weather was sunny, extremely hot with a strong, gusting East wind. Temperatures at 4:00 PM were near 100 degrees Fahrenheit (37 deg C) (thermometer reading). I was heading from the mill to the bush where ZFI [Zeidler Forest Industries Ltd.] had several hoes working to protect culverts and bridges from high runoff. I stopped on the Prince George side of the Highway Bridge on the Dore River as a loud noise was heard upstream. When I looked upstream a large wall of water and debris was coming towards the bridge. The water was careening from side to side reflecting off the trees on the edge of the stream. The water was acting like a slinky that you would shake sideways. I put the truck in reverse to get away from the bridge. Just before the water hit the bridge, much of the main force of water went sideways down the

road towards the housing area. Wood stringers and decks of two of the ZFI bridges at 2 and 6 km cleared (over top of the highway bridge) and went down stream.

As described by Mr. Runtz, subsequent helicopter inspection within the upper watershed identified a snow avalanche that buried the main Dore River channel at an unspecified location to a depth estimated at 40 ft (13 m). The sudden release of water impounded by the snow avalanche deposit was attributed as the source of flooding. Dore River gauge data[4] for May 26, 1986 does not show extreme flood discharge (approximately 4-year return period flows) but is flagged as "E" (Estimated), suggesting lower confidence in the data. It is not known whether the "E" is associated with flood-related damage to the gauge. Based on Mr. Runtz's account, BGC concludes that the flood characteristics as described are typical of an outbreak flood.

Based on the presence of abundant slope-scale landslide landforms and valley geometries that are confined enough for river blockage, BGC concludes that the potential exists for landslide dams to form and fail, with potential for elevated flood or debris flood discharge that could reach the AOI. Based on the account of Mr. Runtz, BGC concludes that there is also potential for elevated flood discharges to occur following the formation and failure of (mostly wet spring) snow avalanche dams. Consideration of such scenarios could form part of Dore River flood frequency analyses.

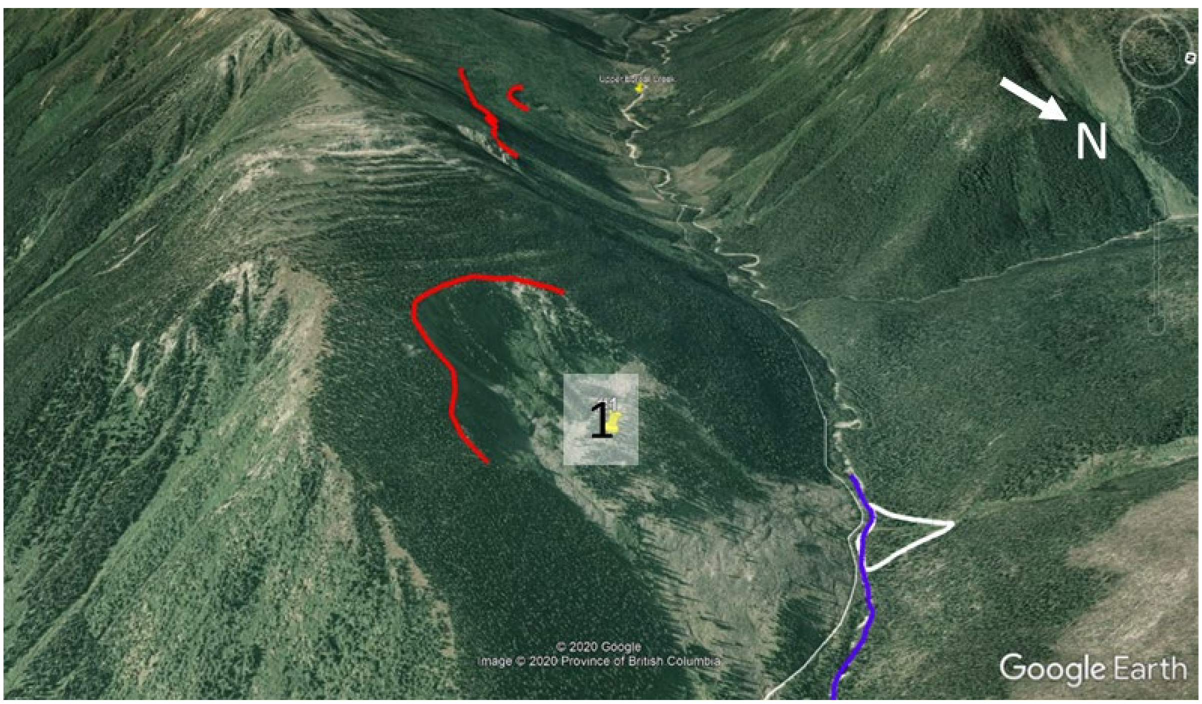


Figure 2-1. Google Earth image of Upper Boreal Creek sub-tributary of Dore River Watershed (Location #1 on Drawing 01) The red line indicates the crest of a slope movement feature that has pushed Upper Boreal Creek towards the north side of the creek (section delineated in blue). A steep creek fan (white outline) is also confining the main stem from the north.

[4] WSC gauge 08KA001.

3. BANK EROSION ASSESSMENT

Bank erosion involves the erosion of sediment from the margins of a river, resulting in bank retreat. Bank erosion may occur gradually; in low gradient, meandering rivers erosion is often concentrated at the outside of bends and is roughly balanced by deposition of eroded material in point bars along the inside bank of downstream bends, enabling the river to maintain a consistent width over time as it shifts across its floodplain (Church, 2006; Fuller, 2007). Erosion may also occur as rapid widening during large flood events. This erosion type is especially common in steeper rivers with non-cohesive bank material (e.g., sand and gravel), and occurs when the sediment at the toe of the bank is fully mobilized by the flow, resulting in undercutting (Eaton, 2006; Darby et al., 2010).

The June 2020 flood caused significant erosion in the form of rapid widening along the reach of the Dore River that extends from Highway 16 to Museum Road (the AOI). This erosion involved both the outward migration of meander bends and general channel widening. An avulsion also occurred, with the river carving a new path on the floodplain in one location.

In the following section BGC presents a historical imagery assessment used to evaluate past erosion within the AOI, as well as bank erosion modelling to predict potential future erosion. The historical assessment is intended to provide context for the 2020 flood event, showing both natural and manmade changes to the river from 1948 to 2020. The bank erosion modelling provides estimates of potential future erosion during a 200-year flood event and was calibrated to reproduce the measured erosion from the June 2020 flood event.

3.1. Historical Imagery Assessment

3.1.1. Qualitative Assessment

BGC used air photos, satellite imagery, and drone photographs from 1948 to 2020 to evaluate changes in the size and position of the Dore River over time. BGC extended the qualitative analysis several hundred meters upstream and downstream of the AOI (Drawings 04 to 07) as notable changes had been recorded upstream of Highway 16 and downstream of Museum Road in historical documentation provided by the RDFFG. The total reach length considered in the qualitative assessment was 3.4 km. The quantitative evaluation of erosion (Section 3.1.3), as well as the bank erosion modelling (Section 3.2, were restricted to the 1.3 km of river length within the AOI, which extends from Highway 16 to Museum Road (Drawing 08 and 09).

Table 3-1 summarizes the imagery used in the historical assessment, as well as notable changes in the Dore River and surrounding land use observed in each image. The imagery used in the historical assessment is shown on Drawings 04 to 07 for eight of the historical assessment years[5], and drone photographs obtained following the June 2020 flood are shown on Drawing 08. Significant changes within the assessment reach are labeled on the drawings.

[5] The 1991 air photo is not shown in the drawings as there was little observable change. However, it was used to estimate erosion over the period from 1987-1991 and 1991-1996 in the quantitative erosion assessment.

Table 3-1. Imagery used in the historical Dore River assessment.

Date	Roll	Photo Numbers	Scale	Description	
				Land Use	Dore River
1946 (Drawing 04)	BC313	95-97	Unknown	• Minimal land clearing aside from an area north of Museum Road on the east side of the river • Museum Road and CN Railway present but Highway 16 not yet built	• No riprap or other alterations noted
1958 (Drawing 04)	BC2510	7, 8	Unknown	• Extensive land clearing on the east side of the river • Dore River Road built on the west side of the river • Sawmill site cleared on the west side of the river	• No riprap or other alterations visible • Minor erosion at the outside of meander bends since 1946 • Expansion of vegetated islands
7/31/1973 (Drawing 05)	BC7505	162, 163	1:15,000	• Highway 16 constructed but bridge not yet present over the Dore River • Extensive residential and industrial development on both sides of the river • Land cleared on the east side of Dore River upstream of Highway 16	• Realignment/channelization of Dore River upstream of Highway 16 and also west of the sawmill (meander bend cut off) • Riprap added intermittently over a stream length of 1.3 km • Berm constructed on left (west) bank upstream of Highway 16 • Erosion at outside of bends in non-channelized areas

<table>
<tr><th rowspan="2">Date</th><th rowspan="2">Roll</th><th rowspan="2">Photo Numbers</th><th rowspan="2">Scale</th><th colspan="2">Description</th></tr>
<tr><th>Land Use</th><th>Dore River</th></tr>
<tr><td>9/26/1976
(Drawing 05)</td><td>BC7894</td><td>136, 137</td><td>1:20,000</td><td>• Highway 16 bridge over Dore River completed</td><td>• Berm suspected to have been constructed along right (east) bank of bend downstream of Highway 16 (1005 Dorval)</td></tr>
<tr><td>6/7/1987
(Drawing 06)</td><td>BCC566</td><td>80-82</td><td>1:15,000</td><td>• Additional residential development on both sides of the river</td><td>• Significant bank erosion throughout reach
○ Island removed by erosion upstream of Highway 16
○ Erosion on right bank of bend downstream of Highway 16 and elimination of berm visible in 1976 (1005 Dorval)
• Sediment deposition visible on floodplain downstream of Museum Road (2500 Museum Rd.)
• Additional mitigation completed in 1986 not visible in the 1987 air photo</td></tr>
<tr><td>8/22/1991</td><td>BCB91105</td><td>53, 54</td><td>1:15,000</td><td>• Little observable change from 1987</td><td>• Little observable change from 1987</td></tr>
<tr><td>8/14/1996
(Drawing 06)</td><td>BCB96100</td><td>204, 205</td><td>1:40,000</td><td>• Land clearing on the west side of the river north of Museum Road</td><td>• Minor erosion throughout the reach
• Formation of vegetated island upstream of CN Railway bridge</td></tr>
</table>

Date	Roll	Photo Numbers	Scale	Description	
				Land Use	Dore River
9/6/2006 (Drawing 07)	BCC06147	37, 38	1:20,000	• Industrial development on the west side of the river north of Museum Road	• Minor bank erosion throughout the reach • Island formation downstream of the Highway 16 bridge and in multiple locations downstream of Museum Road • Riprap less visible than in earlier years
8/19/2019 (Drawing 07)	Google Earth	-	-	• Little observable change from 2006	• Moderate erosion throughout the reach concentrated at outside of meander bends
7/26/2020 (Drawing 08)	Drone photographs	-	-	• No observable change from 2019	• Extensive erosion along the right (east) bank of the meander bend downstream of Highway 16 (1005 Dorval) and across from the former sawmill (1475 and 1655 Dorval) • Limited erosion in areas with riprap

3.1.2. Mitigation History

1958-1973 Channelization

The Dore River was modified between 1958 and 1976, as shown in Drawing 05 and described in Table 3-1. The approximate locations of riprap and berms constructed during this timeframe are shown on Figure 3-1. River modifications during this period involved the realignment of the river to cut off a large meander bend located west of the former sawmill (Drawing 05). The river was also narrowed over a stream length of 400 m upstream of the newly constructed Highway 16 bridge through berm construction on the west side of the river and extensive riprap placement along both banks (Drawing 05; Figure 3-1). Presumably, much of this work was intended to protect existing infrastructure and to create more favorable conditions for further development.

Within the AOI, riprap was added intermittently to maintain the new channel position and to limit erosion. An additional berm appears to have been constructed between 1973 and 1976 along the right (east) bank at the 1005 Dorval property to limit the river width within the bend and to protect water intakes (Drawing 05; Figure 3-1).

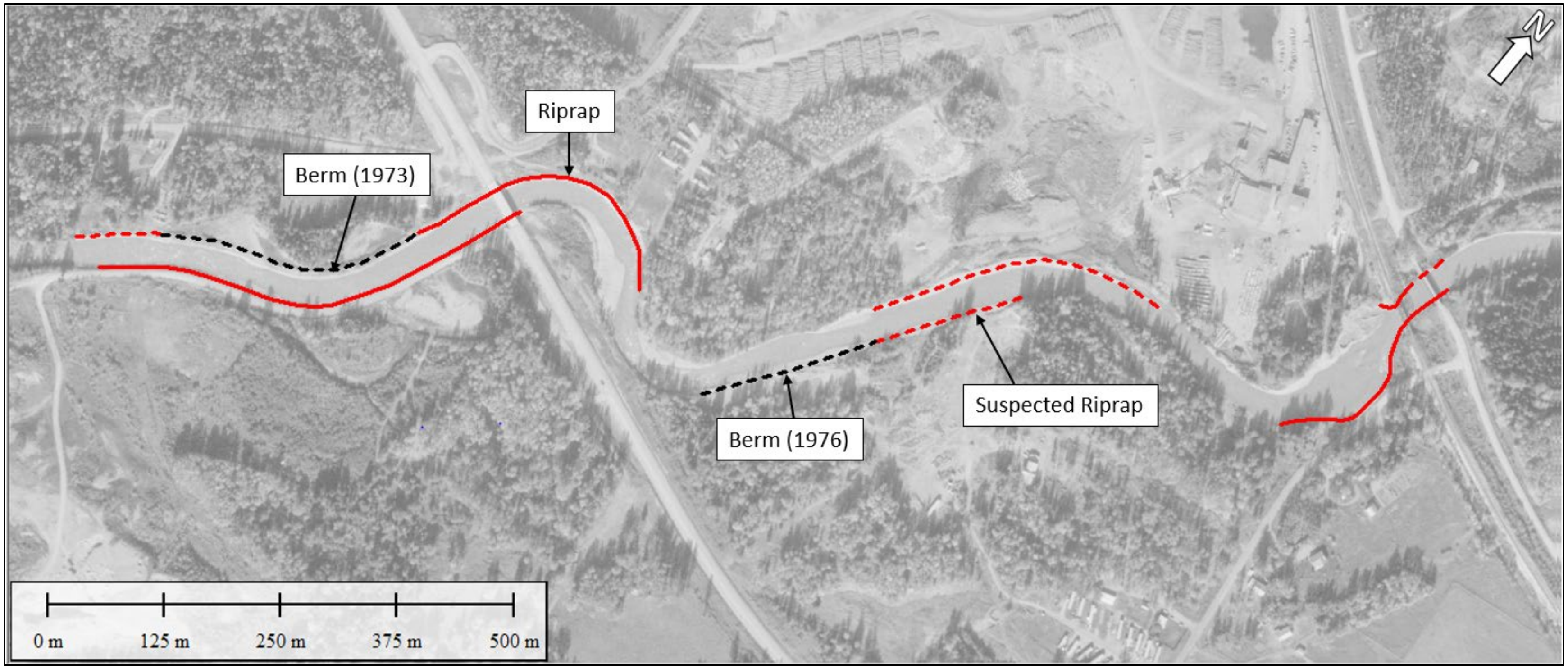


Figure 3-1. Berm and riprap locations visible in 1973 and 1976 air photos. Dashed lines represent suspected riprap or berm locations, and the solid red lines indicate riprap that is clearly visible in the imagery. Image source: 1976 air photo, Government of British Columbia.

<u>1986 Post-flood Mitigation</u>

An outbreak flood occurred on May 26, 1986, as described in Section 2. According to historical documentation provided by RDFFG, the 1986 flood damaged 10 km of the Dore River Forest Service Road (FSR) and caused extensive damage to several properties on the west side of the Dore River upstream of Highway 16 (3317, 3189, and 3311 Dore River Rd. properties; Drawing 06). Erosion of riprap placed during the earlier river channelization (between 1958 and 1976) also occurred in the residential area upstream of Highway 16 (Drawing 06).

Within the AOI, erosion along the left (east) bank of the Dore River damaged the water intakes for the River Bend trailer park (Drawing 06). Similarly, erosion along the right bank eliminated a damaged training berm, resulting in erosion of the 1005 Dorval property and damage to water intakes at the 3115 River Bend Rd. property. Riprap also failed along the right bank further downstream, leading to damage along the 1475 and 1655 Dorval properties (Drawing 06). Overbank flooding occurred on the 2500 Museum Rd. property – located outside of the AOI immediately downstream of Museum Road – and is visible as deposited sediment on Drawing 06.

The most significant damages from the 1986 flood occurred upstream of Highway 16, outside of the current AOI. As a result, most post-flood mitigation was also concentrated outside of the AOI. Extensive in-stream works were completed on the first 7 km of the Dore River FSR, including:

- Road replacement
- Riprap addition in several locations
- Construction of a toe berm in an area with landslide activity at 5.3-5.5 km
- Replacement of two bridges at 2.1 km and 6.35 km.

Within the AOI additional riprap may also have been added along the ZFI property, at the CN Railway and Museum Road bridge crossings, and adjacent to other private properties. According to an October 23, 2020 account from Mr. Eugene Runtz:

> I met with Dave King immediately after the flight and Dave gave permission to push large boulders from the river for Rip Rap and channelize the stream as needed to protect ZFI and other private property… On May 27, rip rapping and channelization of the stream was started on ZFI property only. It was expanded to other private property the next day at the request of Mayor Kolida with the understanding that ZFI may not be compensated for the other property protection. The work took about 3 days for all channelization and rip rapping with a D8 Cat… ZFI was only involved in the riprapping using river boulders and channelization. PEP officials were also involved with angular rock riprapping of the two Highways bridges and CN bridge over the Dore.

BGC requested additional information from RDFFG regarding the extent of the 1986 mitigation, but RDFFG would not have been responsible for a response and did not have any records of these mitigation works. The mitigation efforts described by Mr. Runtz are not visible within the AOI on the 1987 imagery, likely because the riprap was simply added to replace riprap damaged during the flood. As a result, there is no obvious change in the extent of riprap, or channel alignment, between 1976 and 1986 on the available air photos.

3.1.3. Quantitative Assessment

The historical imagery described in Table 3-1 was used to evaluate the amount of riverbank erosion between each image year, as well as changes in island size and flow paths. The quantitative assessment focused on the 1.3 km-long river section located within the AOI. Lidar obtained in October 2020 was first used to orthorectify the 1948 to 2006 air photos[6]. BGC then delineated the location of the channel banks and all mid-channel islands for each image year in a Geographic Information System (GIS). Finally, erosion was estimated by comparing the wetted channel area between image years.

The erosion polygons shown on Drawings 04 to 09 indicate areas that become part of the wetted channel area through riverbank erosion – in other words areas that had changed from land to river – since the previous image. Table 3-2 summarizes the measured erosion within the AOI between each image year. The average erosion represents the total bank erosion within the reach divided by the river length within the AOI (1.3 km) and the maximum erosion represents the largest amount of erosion observed at a single location within the reach. Maximum erosion estimates are also provided for the 1005 Dorval property as well as the 1475 and 1655 Dorval properties, as these areas were subject to the largest amount of erosion from 1973 to 2020 (Drawing 08). Minor island erosion observed in the periods from 1958-1973 and 2019-2020 was not included in the bank erosion estimates.

The highest average and maximum erosion was recorded in 2019-2020, measuring up to 40 m at the 1005, 1475, and 1655 Dorval properties and averaging 11 m throughout the reach (Drawing 08). Throughout the remainder of the image history the average erosion varied between 1 m to 6 m – representing an annual erosion rate of 0.1 m/year to 0.6 m/year – with maximum erosion of 29 m in the period from 1958-1973 and 28 m in the period from 1976-1987 (Table 3-2).

Since channelization (i.e., post-1973) erosion has typically been concentrated along the right bank of the river at the outside of a meander bend located directly downstream of the Highway 16 bridge (1005 Dorval) and within a new bend that has formed across from the former sawmill (1475 and 1655 Dorval). Drawing 08 shows that this erosion represents a re-meandering of the river over time; the river was straightened within the AOI prior to 1973 and has since been progressively increasing its sinuosity through right bank erosion at the 1005, 1475 and 1655 Dorval properties, and left bank erosion between the two bends. The length of the stream centerline has increased by 65 m over the 47-year period, resulting in an increase in the sinuosity from 1.35 to 1.42.

[6] Orthorectification was not required for the 2019 Google Earth imagery and the 2020 drone photographs as they were already georeferenced.

Table 3-2. Measured riverbank erosion within the AOI from 1946 to 2020.

Image Interval Years	Flood Date	Flood Discharge (m^3/s)	Return Period (years)	Average Erosion		Maximum Erosion		
				m	m/year	Reach (m)	1005 Dorval Property	1475 and 1655 Dorval Property
1946-1958[1]	-	-	-	5	0.4	9	0	0
1958-1973	1967	153	28	6	0.4	29	0	0
1973-1976	1974	99	3	1	0.2	7	0	0
1976-1987	1986	112	4	6	0.6	28	17	1
1987-1991	1987	121	6	1	0.3	13	2	2
1991-1996	1991	128	9	2	0.3	12	5	12
1996-2006	1997	114	5	2	0.1	13	3	13
2006-2019	2012	154	30	4	0.3	20	13	20
2019-2020	2020	171	74	11	11	40	39	40

Note:

1. The largest flood during this period is unknown as flow records were not available for all years from 1946 to 1958 at gauge 08KA001.

BGC used hydrometric data from the WSC gauging station located 2.2 km upstream (southwest) of the Highway 16 bridge (08KA001, *Dore River near the Mouth*) to determine the highest instantaneous flood discharge[7] during each image interval (Table 3-2). The return period[8] associated with the largest flood was then compared with the measured erosion over the image interval to develop a regression between flood magnitude and bank erosion (both average and maximum) (Figure 3-2).

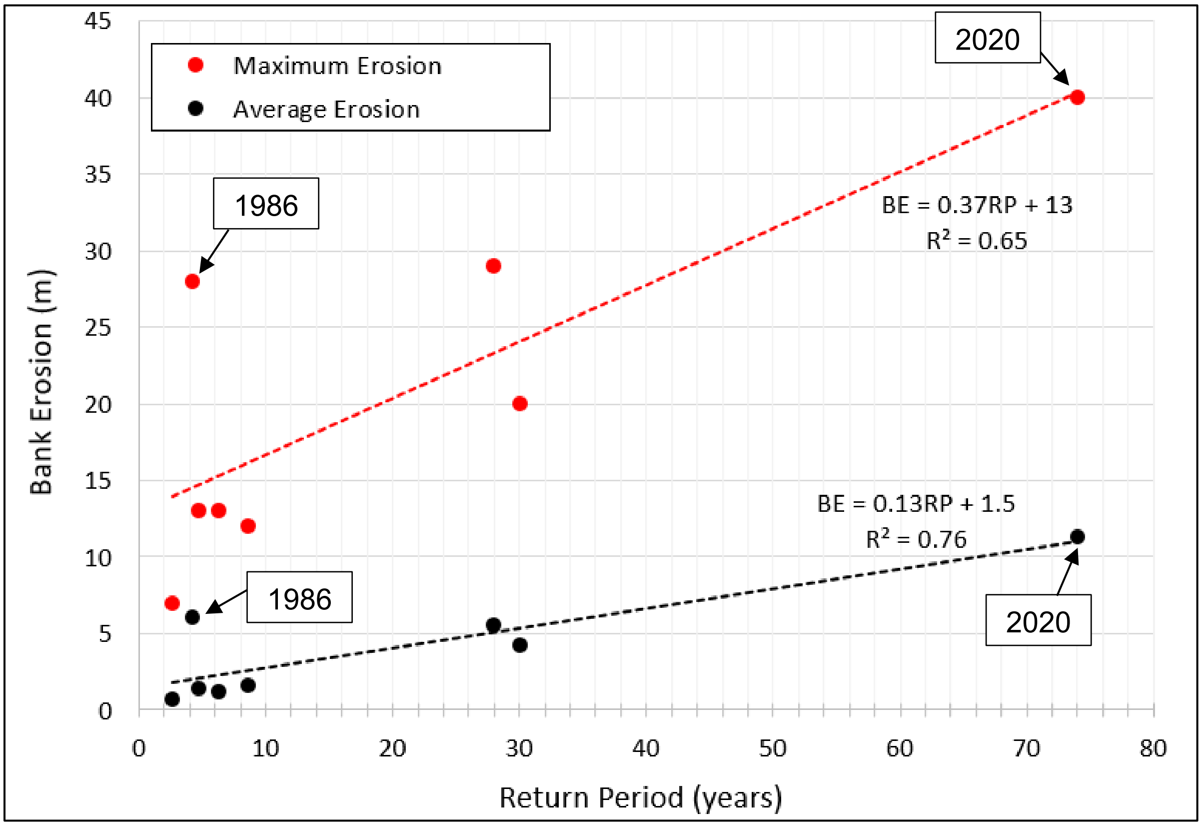


Figure 3-2. Average and maximum erosion compared with flood return period for the years 1958 to 2020.

The analysis indicates that erosion is related to flood magnitude within the Dore River AOI; substantial erosion was observed in the periods containing the three largest floods (1958-1973, 2006-2019, and 2019-2020). A large amount of erosion was also measured in the period from 1976-1987, which contained the dramatic May 26, 1986 outbreak flood described in Section 2 and Section 3.1.2 (Drawing 06). However, the maximum and average erosion for this period far exceed the expected values for a 4-year return period flood event based on the linear regressions presented in Figure 3-2. This apparent discrepancy may represent an under-estimate of the 1986 flood discharge and associated return period; the WSC note that the peak instantaneous discharge of 112 m^3/s is an estimate rather than a recorded value, and BGC believes it likely that

[7] The maximum instantaneous discharge represents the highest flow measured over a 15-minute interval throughout the year.
[8] Return periods for each flood event were provided by McElhanney. The discharge for the 2020 flood event is based on provisional data that has not yet been published by the WSC.

the gauge was damaged during the 1986 events based on the flood description in Section 2 and the gauge location several kilometres upstream of Highway 16.

The quantitative analysis described above assumes that all erosion during an image interval can be attributed to a single flood event. It is possible in some cases that erosion may actually represent the cumulative effect of multiple floods over the period between images, especially as the number of years between images increases. BGC therefore also considered the average annual erosion over each image interval. Table 3-2 shows that the average annual erosion (m/year) was greatest during the periods containing the 1986 outbreak flood (1976-1987) and the June 2020 flood (2019-2020).

BGC also used additional satellite imagery to evaluate the 2020 erosion in greater detail, as two large flood events occurred in a single year. The June 23, 2020 flood was the largest on record with a provisional instantaneous discharge of 171 m^3/s and a return period of 74 years. However, a second flood[9] on September 2, 2020, recorded a provisional instantaneous discharge of 154 m^3/s, making it the second largest flood in recorded history at gauge 08KA001 with a return period of approximately 30 years. A comparison of Sentinel satellite imagery obtained in May, August, and September 2020 confirmed that nearly all of the 2020 erosion could be attributed to the larger flood event on June 23. This was further supported by a comparison of the drone photographs obtained in August 2020 and the lidar obtained in October 2020, which showed little change in response to the September flood. The limited erosion in response to the large September 2020 flood is to be expected, as the earlier June flood widened the channel by an average of 11 m within the AOI, substantially reducing the shear stress (and erosive potential) of the second flood.

3.2. Bank Erosion Modelling

3.2.1. Model Overview

BGC used a probabilistic model to predict the magnitude of future erosion events within the AOI. Bank erosion is a self-limiting process as channel widening lowers the flow depth and shear stress associated with a given flood magnitude. As a result, the maximum amount of bank erosion during a flood can be predicted if channel characteristics (e.g., grain size, channel shape) are known. The model details, inputs, and calibration are described in detail in Appendix B.

The inputs to the model include the existing river geometry, roughness characteristics, and grain size distribution. Table 3-3 summarizes the model input values and the data sources used to determine each value.

[9] The WSC only records the single largest instantaneous maximum discharge each year and would therefore not typically have record of this second large flood event. However, BGC collects and stores all 15-minute instantaneous discharge measurements throughout each year in the RNT for all real-time WSC gauges.

Table 3-3. Model input parameters.

Model Input Parameter	Mean Value	Method
D_{50} Grain Size (m)	0.064 m	The median grain size was estimated from photographs of the bed material taken by McElhanney at 11 locations throughout the AOI and analyzed by Split Engineering (see Drawing 09 for locations).
Gradient (m/m)	0.008 m/m (0.8%)	Average gradient was calculated over a stream length of 1.3 km (from the Highway 16 bridge to the Museum Road bridge) using October 2020 lidar.
Channel Width (m)	15-60 m (2019) 20-108 m (2020 – total width) 20-56 m (2020 – active width)	Measured for each cross section using 2019 Google Earth imagery for model calibration, and using 2020 lidar and drone photographs for modelling the future erosion.
Shields Number (dimensionless)	0.08	A threshold Shields value of 0.1 was initially used based on research by Eaton et al. (2020). The value was then adjusted to calibrate the model, resulting in a final value of 0.08.
Manning's roughness coefficient (dimensionless)	0.045	This mean roughness value is typical of mountain rivers with gravel- to cobble-sized channel bed material (Chow, 1959).
Discharge (m^3/s)[1]	171 (calibration) 189 (200-year)	The model was run with the June 23, 2020 instantaneous discharge of 171 m^3/s for calibration. A 200-year instantaneous discharge of 189 m^3/s was used to model future erosion.

Note:

1. Discharge was not varied in the Monte Carlo simulation.

The model was calibrated using the measured channel widths from the 2019 Google Earth imagery at cross sections located within the bends at the 1005, 1475 and 1655 Dorval properties, where the largest amount of erosion occurred in 2020. Although the maximum erosion measured was 39 m at the 1005 Dorval property and 40 m at the 1475 and 1655 Dorval properties (Table 3-2), BGC used the average erosion throughout each bend – 27 m at the 1005 Dorval property and 30 m at the 1475 and 1655 Dorval properties – in the model calibration, rather than the most extreme erosion at the bend apex. The calibration process is described in more detail in Appendix B.

3.2.2. Modelled Scenarios

River widening during large flood events may reduce erosion during subsequent floods, as there are lower shear stresses (and less erosive potential) for a given flood magnitude in the widened river (Davidson & Eaton, 2018). The effect of recent widening was evident during the September 2, 2020 flood, which caused little erosion despite having the second highest recorded discharge since gauge 08KA001 first became operational in 1949. As a result, erosion modelling based on the recently-widened river geometry is likely to be unconservative (i.e., to underestimate future erosion).

As time passes following a large flood event, rivers typically narrow through vegetation growth on exposed bars and mid-channel islands (Bertoldi, Drake, & Gurnell, 2011; Davidson & Eaton, 2018). Figure 3-3 shows that abundant sediment deposits were present within the Dore River AOI following the 2020 flooding. These exposed bars have the potential to form islands or to extend the floodplain into the river in the future, resulting in narrowing. To account for the recent widening on the Dore River – and the potential for future narrowing – BGC considered the following two scenarios in the predictive bank erosion modelling:

- Scenario 1: existing widened river geometry (i.e., total width)
- Scenario 2: future narrowed geometry (i.e., active width).

In the first scenario future erosion was predicted based on the existing 2020 river width within the AOI (see Figure 3-3 for an example of total and active width). In the second scenario BGC considered only the active channel width at each cross section.

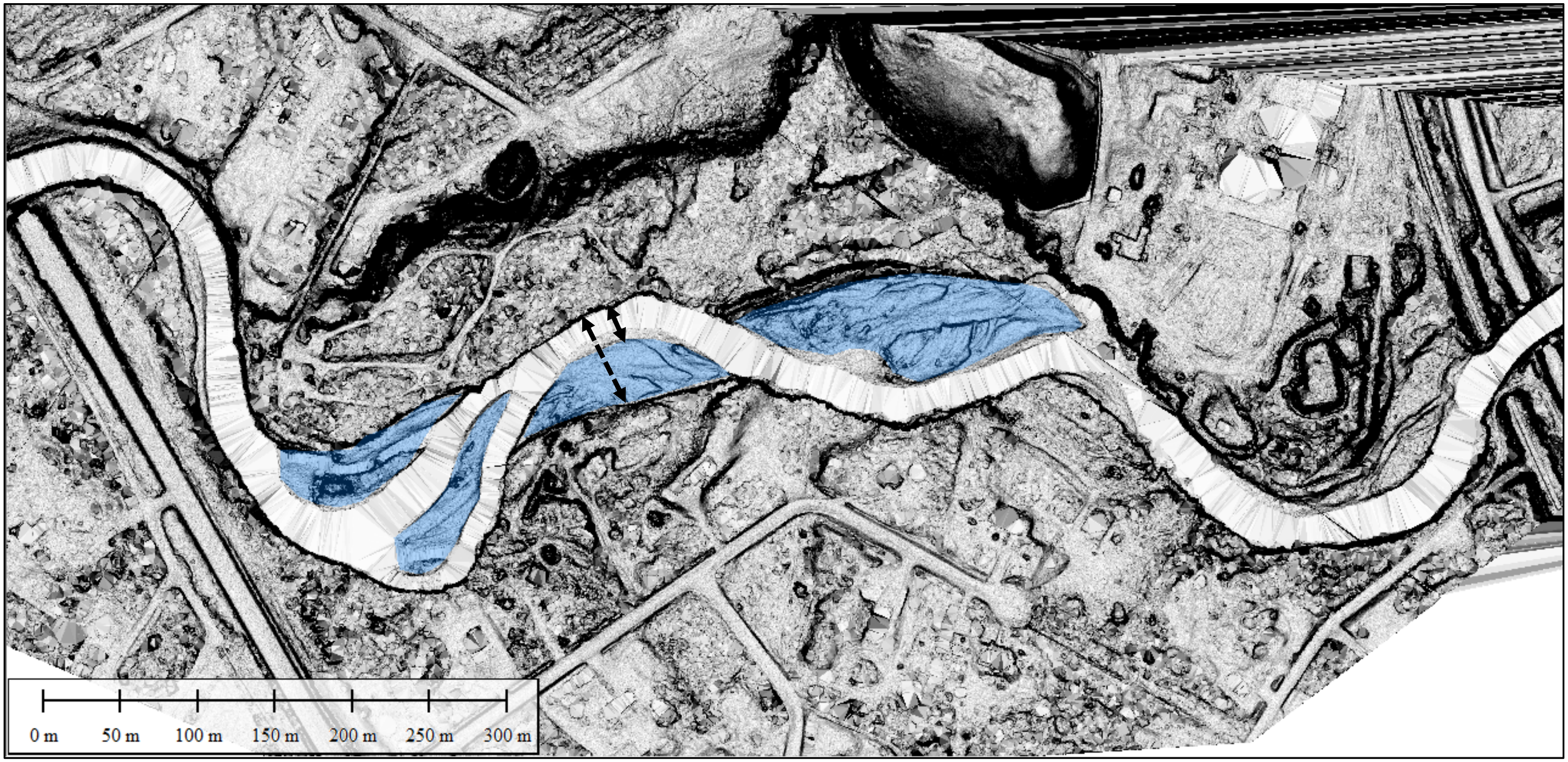


Figure 3-3. DEM hillshade based on October 2020 lidar data provided by McElhanney. Blue polygons show exposed sediment deposits or islands within the Dore River AOI. The black dashed arrow represents the total river width and the black solid arrow represents the active river width.

Figure 3-4. Riprap locations observed during a post-flood site visit by McElhanney are shown (blue markers) with flow direction indicated by the blue arrows. Imagery source: inset photographs obtained by McElhanney on November 3, 2020, and background imagery from Google Earth, August 19, 2019.

3.2.3. Results

The predicted erosion extents are shown in Drawing 09 for a 200-year flood event for both modelled scenarios. The extents represent the median estimated erosion (i.e., 50th percentile) for each scenario. The median erosion ranges from 0 m to 50 m during a 200-year flood event under the current (i.e., widened) river geometry, and increases to 11 m to 58 m if only the active width is considered. The latter is considered a more realistic representation of future erosion as rivers typically narrow over the decades following flood events through vegetation colonization of exposed sediment deposits (Bertoldi et al., 2011; Davidson & Eaton, 2018).

As a comparison, the maximum erosion during a 200-year flood according to the linear regression presented in Figure 3-2 would be 87 m, with average erosion throughout the reach of 28 m. These historically-based estimates of erosion do not account for the higher elevation topography encountered as erosion progresses, the widened channel geometry following the 2020 flood, or the self-limiting nature of erosion during extreme flood events. As a result, the future erosion is likely overestimated based on the historical assessment and the results from the predictive modelling are preferred.

Erosion is a stochastic process, and the distribution of erosion between the two banks is unknown. It was therefore assumed that the erosion could occur entirely on either side of the existing riverbank. However, erosion is likely to occur preferentially at the outside of bends, resulting in conservative estimates of erosion along the inside of bends or within straight reaches where erosion may be more evenly divided.

Riprap also remains present at some locations within the AOI (Figure 3-4) and is likely to provide some degree of continued protection where it remains effective. The combination of higher elevation terrain and riprap, for example, limited the amount of erosion within the bend immediately downstream of Highway 16 during the June 2020 flood event (Drawing 08). Photographs obtained by McElhanney in November 2020 (Figure 3-4) show that the riprap remains present within the bend, though its effectiveness is unclear.

3.3. Discussion and Conclusions

3.3.1. Historical Assessment

The historical assessment presented in Section 3.1 showed that significant bank erosion has occurred at multiple times in the past along the Dore River. Prior to 1973 the channel contained no visible mitigations (e.g., riprap) and had a higher sinuosity, with a large meander bend located to the west of the former sawmill. The Dore River and surrounding landscape was modified artificially in the period between 1958 and 1976. Over this 18-year period Highway 16 was constructed across the Dore River and extensive residential and industrial development occurred within the AOI. The Dore River was channelized within the AOI, as well as upstream of the Highway 16 bridge, with alterations including narrowing and realignment of the river upstream of the Highway 16 bridge and upstream (west) of the former sawmill (Drawing 05). The narrowing and straightening of the river, which increased the river gradient, increased the flow velocity and shear stress (and therefore the erosional potential) associated with subsequent flood events.

Since the channelization (i.e., post-1976) multiple erosion events have occurred. The most significant erosion is attributed to the outbreak flood in 1986 (Drawing 06) and the June 23, 2020 flood (Drawing 08), though substantial erosion also occurred over the period from 2006-2019, likely in response to a 30-year flood in 2012 (Drawing 07). BGC understands that additional mitigation efforts were undertaken in response to the 1986 outbreak flood. Based on historical documentation provided by RDFFG these efforts were largely concentrated upstream of the AOI to repair damages to the Dore River FSR. Although riprap was also added to the channel banks within the AOI, it likely simply replaced riprap damaged during the 1986 flood; no change is channel configuration or riprap extent is visible between the 1976 and 1987 air photos.

Since channelization (i.e., post-1976), erosion has concentrated along the right bank of the river at the outside of a meander bend located directly downstream of the Highway 16 bridge (1005 Dorval property) and within a new bend that has formed across from the former sawmill (1475 and 1655 Dorval properties). The result has been return to more natural meandering conditions within the artificially straightened section of the river located in the AOI; the length of the stream centerline has increased by 65 m over the 47-year period, resulting in an increase in the sinuosity from 1.35 to 1.42.

The increased meandering of the Dore River over time is consistent with the natural pattern of erosion observed in the laboratory experiments conducted at UBC upon which the probabilistic modelling of future erosion is based (Eaton et al., 2017; Eaton et al., 2020). In these experiments, the researchers started the experiments with an artificially straight, rectangular channel, which is similar to the channelized reach of the Dore River in the 1973 and 1976 air photos (Figure 3-5). Over the course of a single flood event the experiments conducted by Eaton et al. (2020) showed that the sinuosity of the channel centerline increased through erosion of the channel banks, with the eroded material typically depositing within the original channel (Figure 3-5). The result was a transition from an artificially straight experimental river to a meandering river flow path.

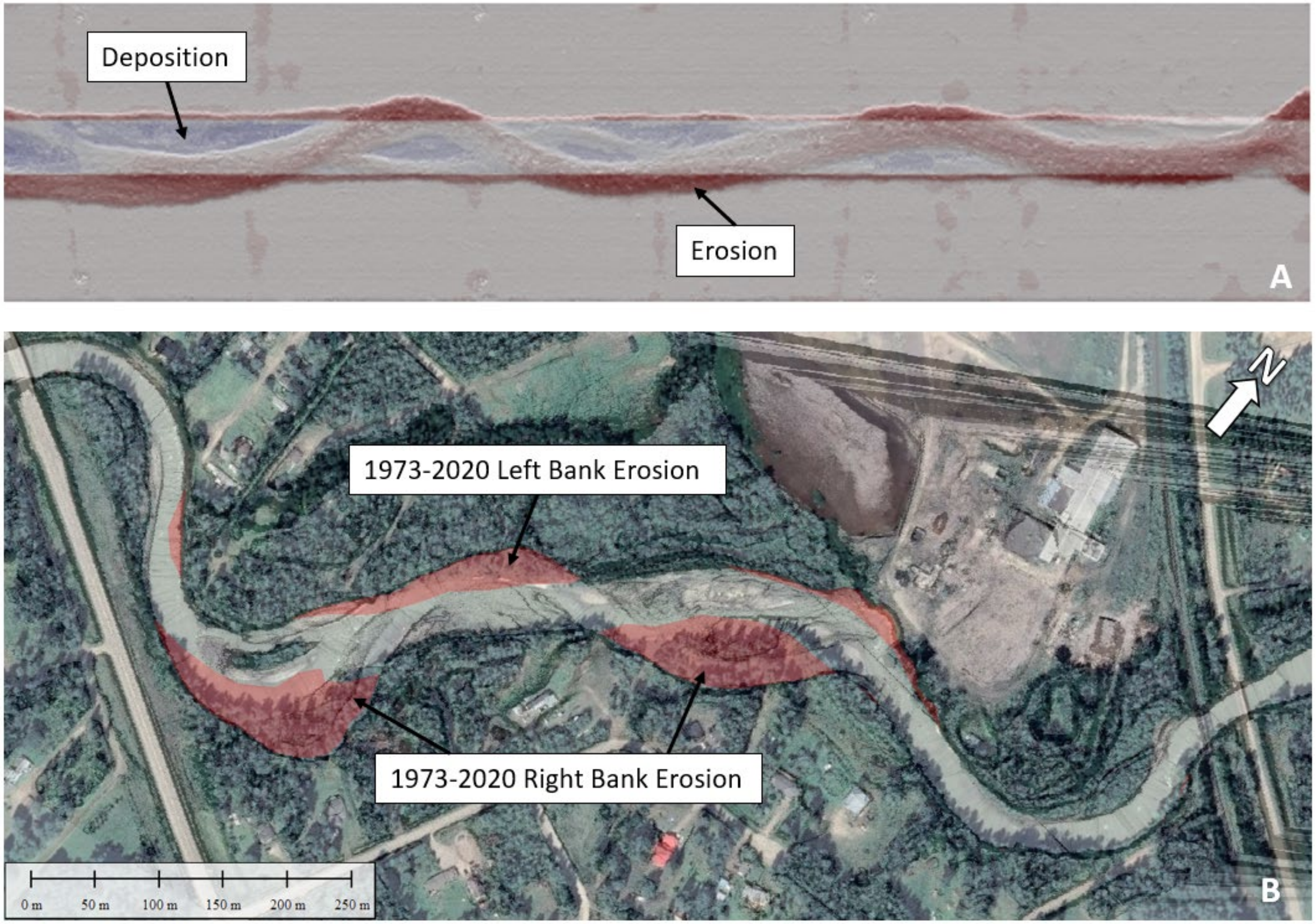


Figure 3-5. In A) red polygons represent erosion and blue polygons show deposition following flooding in experiments conducted by Eaton et al. (2020). In B) red polygons indicate erosion observed between 1973 and 2020. Imagery source: Google Earth, August 19, 2020, and October, 2020 lidar DEM hillshade provided by McElhanney.

3.3.2. Predicted Future Erosion

BGC used a probabilistic model to predict potential future erosion within the Dore River AOI. The model was first calibrated by simulating the June 2020 flood discharge (171 m^3/s) using 2019 river widths measured from Google Earth imagery. BGC then used the calibrated model to predict future erosion based on the current (i.e., post-flood) channel geometry during a 200-year flood event. As river widening during large flood events may reduce erosion during subsequent floods, predictions based on the widened 2020 river geometry are relatively unconservative and may under-predict erosion. BGC also modelled the future 200-year erosion based on the active channel widths measured from October 2020 lidar data; this involved excluding parts of the river with large sediment deposits which may become vegetated islands or floodplain in the future.

The resulting 200-year erosion predictions for both scenarios are shown on Drawing 09. Erosion is unlikely to impact properties on the west side of the river due to higher elevation terrain throughout much of the AOI and the limited development on the west side of the river within the floodplain. Erosion is predicted to occur on the west side of the bend (i.e., left bank) located immediately downstream of Highway 16, though photographs obtained by McElhanney in November 2020 show that riprap remains present within the bend. While this riprap may limit erosion within the bend relative to the model predictions (Drawing 09), the effectiveness of the riprap is unclear. Erosion does, however, have the potential to continue to impact several properties along the east side of the river within the AOI in the future, extending from the 1005 Dorval property to the downstream extent of the 1475 and 1655 Dorval properties (Drawing 09).

3.3.3. Conclusions

BGC conducted a qualitative and quantitative historical assessment of erosion within the Dore River AOI, as well as predictive modelling of future erosion. The main conclusions from the analyses are:

- The Dore River was artificially modified significantly between 1958 and 1976. Over this period the river was narrowed, realigned, and reinforced with riprap and gravel berms, hence disturbing natural channel pattern and evolution.
- Over the subsequent period from 1976 to present the river widened and eroded at its margins, most notably along the right bank at the 1005, 1475 and 1655 Dorval properties, and along the left bank between the two properties.
- Erosion was greatest during the periods with the largest floods, and flood magnitude was correlated to both the average erosion within the AOI and the maximum erosion extent at specific locations.
- Significant erosion occurred in response to the 1986 flood event despite a low recorded discharge and associated return period (4-year). BGC believes this may be due to gauge malfunction during the outbreak flood. Mitigation works conducted in response to the 1986 flood were mainly concentrated upstream of the AOI along the Dore River FSR and are not visible within the AOI.
- The pattern of erosion has resulted in a return to meandering conditions of the river over time since the river was straightened in 1958-1976. This is a natural tendency of a river in

this environment. The sinuosity of the channel centerline has increased, resulting in a longer flow path. This adjustment to straightening is a typical river response and is consistent with laboratory experiments as well.

- Predictive modelling shows that erosion extents could vary from 0 m to 50 m during a 200-year flood event (depending on the location within the AOI) if the river maintains its current widened geometry in the future.
- If the river narrows over time – either naturally or due to mitigation efforts – the predicted erosion during a 200-year flood event will increase to 10 m to 60 m based on the extent and location of deposits within the river in October 2020.
- The modelling does not account for potential future impacts of climate change, which may increase the peak discharge – and erosion – associated with future flood events.
- Erosion has the potential to impact the properties on the west side of the river immediately downstream of the Highway 16 bridge and properties along the east side of the river extending from the 1005 Dorval property to the CN Railway bridge.
- The modelled erosion shows the maximum potential erosion for both banks. The actual erosion will likely concentrate at the outside of existing bends, which are likely to erode to nearly the full modelled extent, while less erosion is likely to occur at the inside of bends. As a result, the pattern of future erosion is likely to continue to increase the sinuosity of the river centerline (i.e., continued re-meandering of the straightened river).
- Riprap remains present intermittently within the AOI and may limit the predicted erosion in some locations. For example, it appears to have limited the erosion during the 2020 flood at the bend immediately downstream of Highway 16. Although it remains present throughout that bend, its integrity and effectiveness are unclear.
- An avulsion that occurred near the 1475 and 1655 Dorval properties was located within a historical flow path of the river, visible in the 1948 air photo. This flow path may be reactivated in the future.
- Previous engineering works completed in 1958 to 1976 (and potentially reinforced in 1986) narrowed and straightened the river, resulting in higher flow velocities and shear stress for a given flood flow and amplifying erosion. Future mitigation efforts should maintain a wider river geometry and work with – rather than against – the natural tendency of the river to meander.

4. CLOSURE

BGC Engineering Inc. (BGC) prepared this document for the account of McElhanney. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

As a mutual protection to our client, the public, and ourselves all documents and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding our documents and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval. A record copy of this document is on file at BGC. That copy takes precedence over any other copy or reproduction of this document.

Yours sincerely,

BGC ENGINEERING INC.
per:

for

2021-03-10

Sarah Davidson, Ph.D., P.Geo.
Fluvial Geomorphologist

Kris Holm, M.Sc., P.Geo.
Principal Geoscientist

Reviewed by:

Hamish Weatherly, M.Sc., P.Geo.
Principal Hydrologist

KH/HW/mj/mm

Attachments: Appendix A - List of Historical Air Photos
Appendix B - Bank Erosion Modelling
Drawings

REFERENCES

Bertoldi, W., Drake, N.A., & Gurnell, A.M. (2011). Interactions between river flows and colonizing vegetation on a braided river: Exploring spatial and temporal dynamics in riparian vegetation cover using satellite data. *Earth Surface Processes and Landforms 36,* 1474-1486. https://doi.org/10.1002/esp.2166

Bufe, A., Turowski, J.M., Burbank, D.W., Paola, C., Wickert, A.D., & Tofelde, S. (2019). Controls on the lateral channel-migration rate of braided channel systems in coarse non-cohesive sediment. *Earth Surface Processes and Landforms, 44,* 2823-2836. https://doi.org/10.1002/esp.4710

Chow, V.T. (1959). *Open Channel Hydraulics*: New York: McGraw-Hill.

Church, M. (2006). Bed material transport and the morphology of alluvial rivers. *Annual Review of Earth and Planetary Science, 34,* 325-354. https://doi.org/10.1146/annurev.earth.33.092203.122721

Darby, S.E., Trieu, H.Q., Carling, P.A., Sarkkula, J., Koponen, J., Kummu, M., Conlan, I., & Leyland, J. (2010). A physically based model to predict hydraulic erosion of fine-grained riverbanks: The role of form roughness in limiting erosion. *Journal of Geophysical Research 115,* F04003. https://doi.org/10.1029/2010JF001708

Davidson, S.L., & Eaton, B.C. (2018). Beyond regime: A stochastic model of floods, bank erosion, and channel migration. *Water Resources Research, 54(9),* 6282-6298. https://doi.org/10.1029/2017WR022059

Eaton, B., Mackenzie, L., Jakob, M., & Weatherly, H. (2017). Assessing erosion hazards due to floods on fans: Physical modelling and application to engineering challenges. *Journal of Hydraulic Engineering, 143(8).* https://doi.org/10.1061/(ASCE)HY.1943-7900.0001318

Eaton, B.C., Mackenzie, L., Booker, W. (2020). Channel stability in steep gravel-cobble streams is controlled by the coarse tail of the bed material distribution. *Earth Surface Processes and Landforms, 45(14),* 3639-3652. https://doi.org/10.1002/esp.4994

Fuller, C. (2007). Geomorphic work during a “150-year” storm: Contrasting behaviors of river channels in a New Zealand catchment. *Annals of the Association of American Geographers 97(4)*, 665-676. https://doi.org/10.1111/j.1467-8306.2007.00576.x

Mackenzie, L.G., Eaton, B.C., & Church, M. (2018). Breaking from the average: Why large grains matter in gravel-bed streams. *Earth Surface Processes and Landforms, 43(15),* 3190-3196. https://doi.org/10.1002/esp.4465

Province of British Columbia (BC) 2014. BC Bedrock Geology online web map. Accessed November 2020. Source: https://catalogue.data.gov.bc.ca/dataset/ef8476ed-b02d-4f5c-b778-0d44c9126144

Runtz Forest Management Ltd. (October 23, 2020). *1986 Flooding of the Dore River and Subsequent Riprapping*. Letter provided to Kristine Drader.

APPENDIX A
LIST OF HISTORICAL AIR PHOTOS

Airphoto No.	Year	Airphoto No.	Year	Airphoto No.	Year
BC2510:6-9	1960	BC7512:92-98	1975	BCB91120:270-268	1991
BC2511:49-47	1960	BC7514:116-119	1975	BCB91120:41-44	1991
BC2518:59-54	1960	BC7514:86-81	1975	BCB96100:198-205	1996
BC2519:35-40	1960	BC7516:248-261	1975	BCB96100:99-97	1996
BC2520:93-86	1960	BC7517:151-142	1975	BCB97029:122-129	1997
BC2521:20-42	1960	BC7517:177-185	1975	BCB97029:85-81	1997
BC2522:75-55	1960	BC7894:136-138	1978	BCC06145:196-201	1961
BC313:103-95	1947	BC7894:215-212	1978	BCC06145:205-206	1961
BC313:22-25	1947	BC7895:122-111	1978	BCC06146:192-183	1961
BC313:39-35	1947	BC7895:204-216	1978	BCC06146:217-228	1961
BC313:85-89	1947	BC7895:33-37	1978	BCC06146:63-60	1961
BC314:36-43	1947	BCB91100:207	1991	BCC06146:97-103	1961
BC314:53-47	1947	BCB91100:210-209	1991	BCC566:113-118	1987
BC320:64-68	1947	BCB91100:222-220	1991	BCC566:12-7	1987
BC7505:164-161	1975	BCB91105:140-150	1991	BCC566:132-126	1987
BC7505:199-203	1975	BCB91105:223-216	1991	BCC566:148-153	1987
BC7505:212-216	1975	BCB91105:26-39	1991	BCC566:156	1987
BC7512:101-110	1975	BCB91105:50-55	1991	BCC566:30-37	1987
BC7512:237-223	1975	BCB91105:84-71	1991	BCC566:52-41	1987
BC7512:59-54	1975	BCB91117:107-113	1991	BCC566:70-82	1987
BC7512:72-64	1975	BCB91117:48-43	1991	BCC566:97-83	1987

APPENDIX B
BANK EROSION MODELLING

B-1 MODEL OVERVIEW

BGC used a probabilistic model to predict the magnitude of future erosion events within the AOI. The model builds upon research conducted at the Biogeomorphic Experimental Laboratory at the University of British Columbia (Eaton, Mackenzie, Jakob, & Weatherly, 2017; Davidson & Eaton, 2018; Mackenzie, Eaton, & Church, 2018; Eaton, Mackenzie, & Booker, 2020). The model relies on the following assumptions:

- Bank erosion occurs when coarse material on the riverbed is mobilized, as destabilization leads to undercutting of the banks and rapid retreat.
- The threshold for erosion can be defined in terms of the critical shear stress, τ_c required to fully mobilize the coarse fraction (D_{84})[10] of the bed material.
- Erosion occurs rapidly during a single flood event and proceeds until the flow depth and shear stress decline back to the critical value, leading to re-stabilization of the coarse fraction of the bed material (D_{84}) and preventing further widening. As a result, the magnitude of bank erosion can be predicted based on flood discharge.

Figure B-1 shows a conceptual representation of the model used in the analysis. As reach-averaged shear stress is directly proportional to average channel depth, the threshold for widening is expressed in terms of a critical depth. Figure B-1 shows that the river remains stable until the critical depth is reached. Once the critical depth has been exceeded, the river widens until the depth reduces back to the critical depth and the bed re-stabilizes, preventing further erosion.

Laboratory experiments by Eaton et al. (2020) show that the threshold for river widening occurs at a dimensionless shear stress (i.e., Shields Number) of approximately 0.1, when considered relative to the median riverbed grain size (D_{50}). This is two to three times the shear stress required to entrain the D_{50} (i.e., initiate sediment transport) and approximately equal to the shear stress required to fully mobilize the D_{84}. The experiments showed that the channel banks remained stable when as much as 80% of the sediment on the bed surface was in motion, and only widened when the coarse fraction was entrained by the flow (Eaton et al., 2020). Widening typically progressed until the dimensionless shear stress reduced back to a value of approximately 0.1.

[10] It can also be expressed in terms of the median grain size (D_{50}) for convenience but exceeds the shear stress required to simply mobilize the D_{50} (i.e., the shear stress needed for in-channel sediment transport) by two to three times.

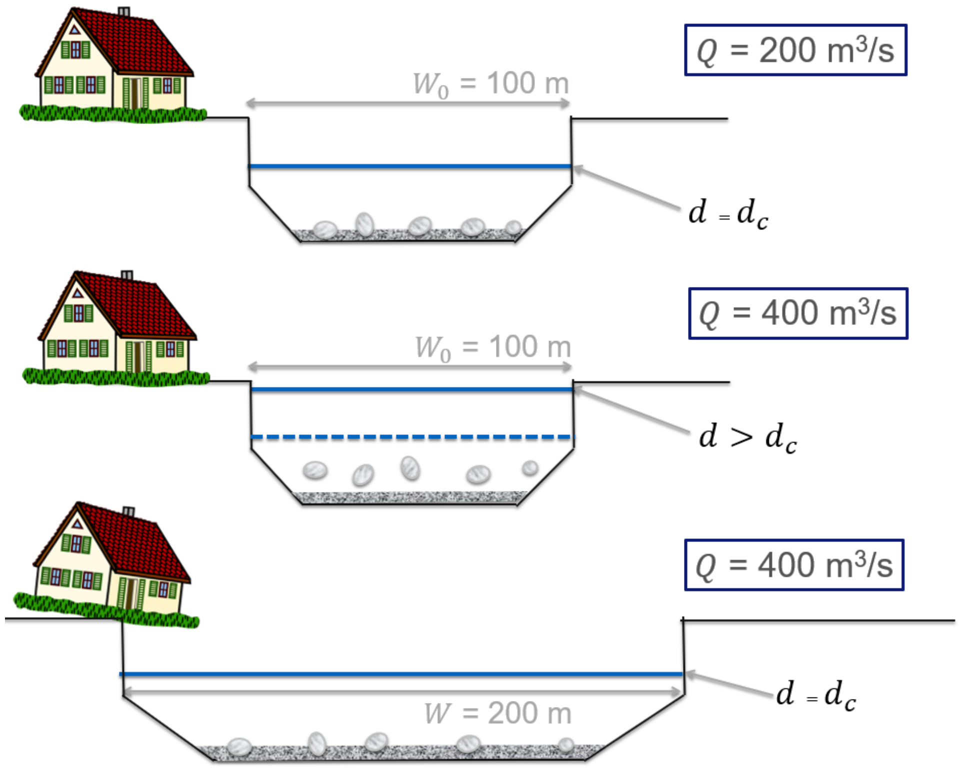


Figure B-1. A simplified schematic showing the approach used to model widening on the Dore River. The riverbed and banks become unstable when the critical depth is exceeded as the coarse material on the channel bed is mobilized by the flow. The channel then widens until the depth decreases back to the critical value and the coarse material re-stabilizes.

BGC used the threshold described above to estimate the critical depth (d_c) for initiation of channel widening:

$$d_c = \frac{0.1 \cdot (\rho_S - \rho_f) D_{50}}{\rho_f S} \quad \text{[Eq. B-1]}$$

where ρ_S represents the sediment density (2,650 kg/m^3), ρ_f is the density of the flow, and S is the gradient (i.e., slope) of the river. In the case of clear-water floods the flow density ρ_f is simply equal to the density of water (1,000 kg/m^3).

The critical discharge (Q_c) was then estimated using Manning's equation:

$$Q_c = \frac{1}{n} {d_c}^{1.67} S^{0.5} W_0 \quad \text{[Eq. B-2]}$$

where S is the channel gradient, W_0 is the pre-flood channel width, and n is Manning's roughness coefficient. Once the critical flow is established, the amount of bank erosion E_{total} required for the river to re-stabilize can be estimated based on the ratio of the flood discharge (Q_i) to the critical discharge (Eaton et al., 2017):

$$E_{total} = W_0 \left(\frac{Q_i}{Q_c} - 1 \right) \quad \text{[Eq. B-3]}$$

B-2 MODEL SETUP AND CALIBRATION

The model was run for 15 cross sections spanning a stream length of 1.3 km from the Highway 16 bridge to the Museum Road bridge. BGC used a Monte Carlo[11] approach to predict erosion; the model was run 1,000 times with the model inputs (Table 3-3) selected randomly from a normal distribution of possible values. This approach explicitly incorporates variability in model inputs, and unlike deterministic models, provides probabilistic estimates of bank erosion.

The model was calibrated using the measured channel widths from the 2019 Google Earth imagery at cross sections located within the bends at the 1005, 1475, and 1655 Dorval properties, where the largest amount of erosion occurred in 2020. The model was run with the June 23, 2020 discharge of 171 m^3/s, and the Shields number was adjusted to reproduce the average erosion measured within these two bends. Although the maximum erosion measured was 39 m at the 1005 Dorval property and 40 m at the 1475 and 1655 Dorval properties (Table 3-2), BGC used the average erosion throughout each bend – 27 m at the 1005 Dorval property and 30 m at the 1475 and 1655 Dorval properties – in the model calibration, rather than the most extreme erosion at the bend apex. The resulting calibrated model used a Shields number of 0.08.

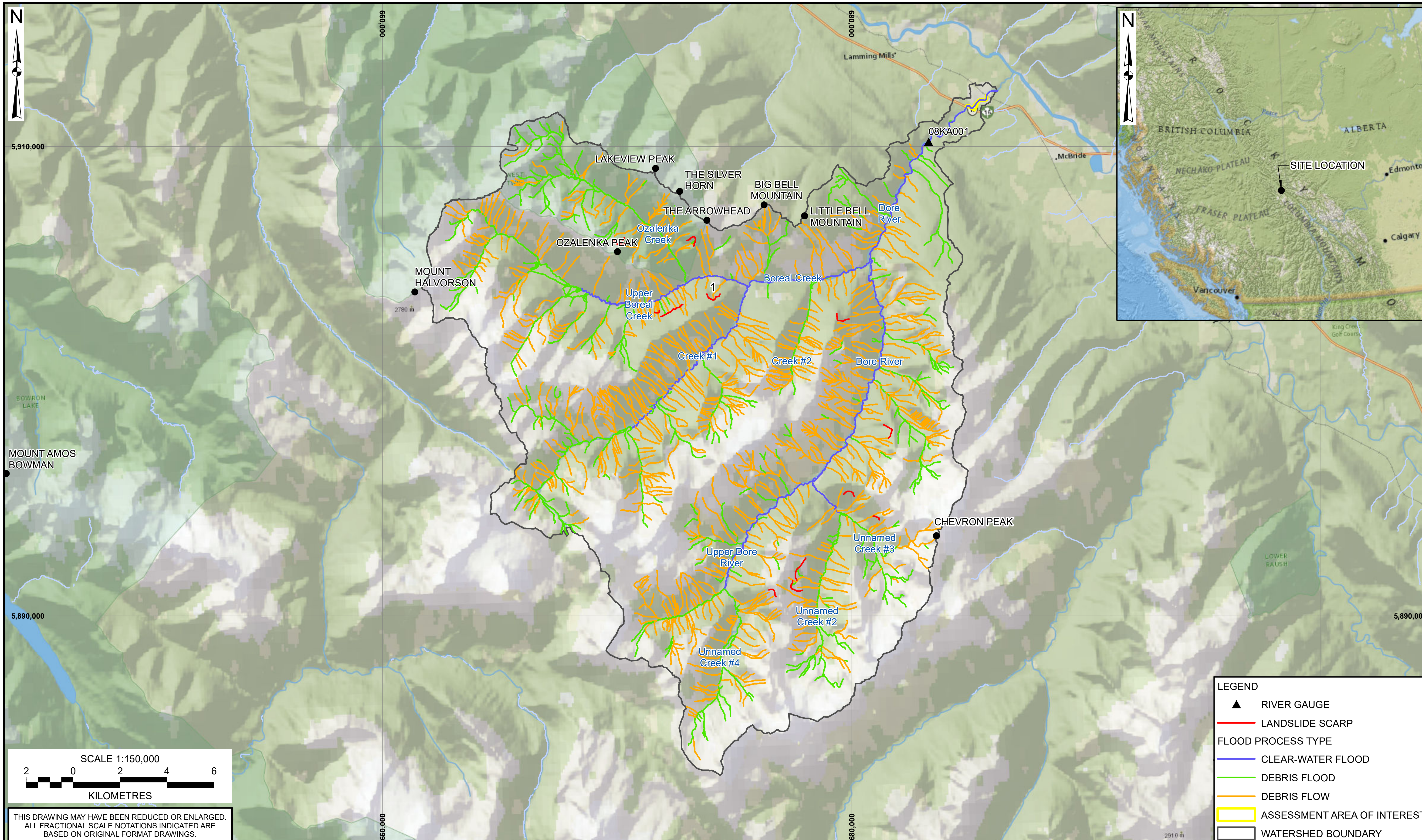
B-3 TOPOGRAPHIC ADJUSTMENT

BGC used the calibrated model to estimate the potential future erosion during a 200-year flood event. Research on rivers with non-cohesive banks shows that the actual magnitude of erosion that occurs is dictated by the elevation of the surrounding landscape relative to the riverbed (Bufe, Turowski, Burbank, Paola, Wickert, & Tofelde, 2019). Assuming that the same volumetric rate of bank erosion occurs, a river surrounded by higher elevation topography will experience a lower total erosion distance (E_{total}) than one with lower elevation topography during the same flood event. BGC therefore adjusted the predicted erosion to account for higher elevations in some areas, including a terrace on the west side of the river.

The topographic adjustment was not considered in the model calibration as the terrain elevations within the eroded areas was not known prior to the June 23, 2020 flood (i.e., pre-flood lidar is not available) and the bends used to calibrate the model are located adjacent to relatively low terrain, limiting the need for topographic adjustment in the calibration locations.

[11] Monte Carlo methods (or experiments) are based on computational algorithms that rely on repeated random sampling to obtain numerical results. It is used to solve problems that are deterministic in principle.

DRAWINGS



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. COORDINATE SYSTEM IS NAD83 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:150,000
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	KH
APPROVED:	-

CLIENT: MCELHANNEY LTD.

BGC

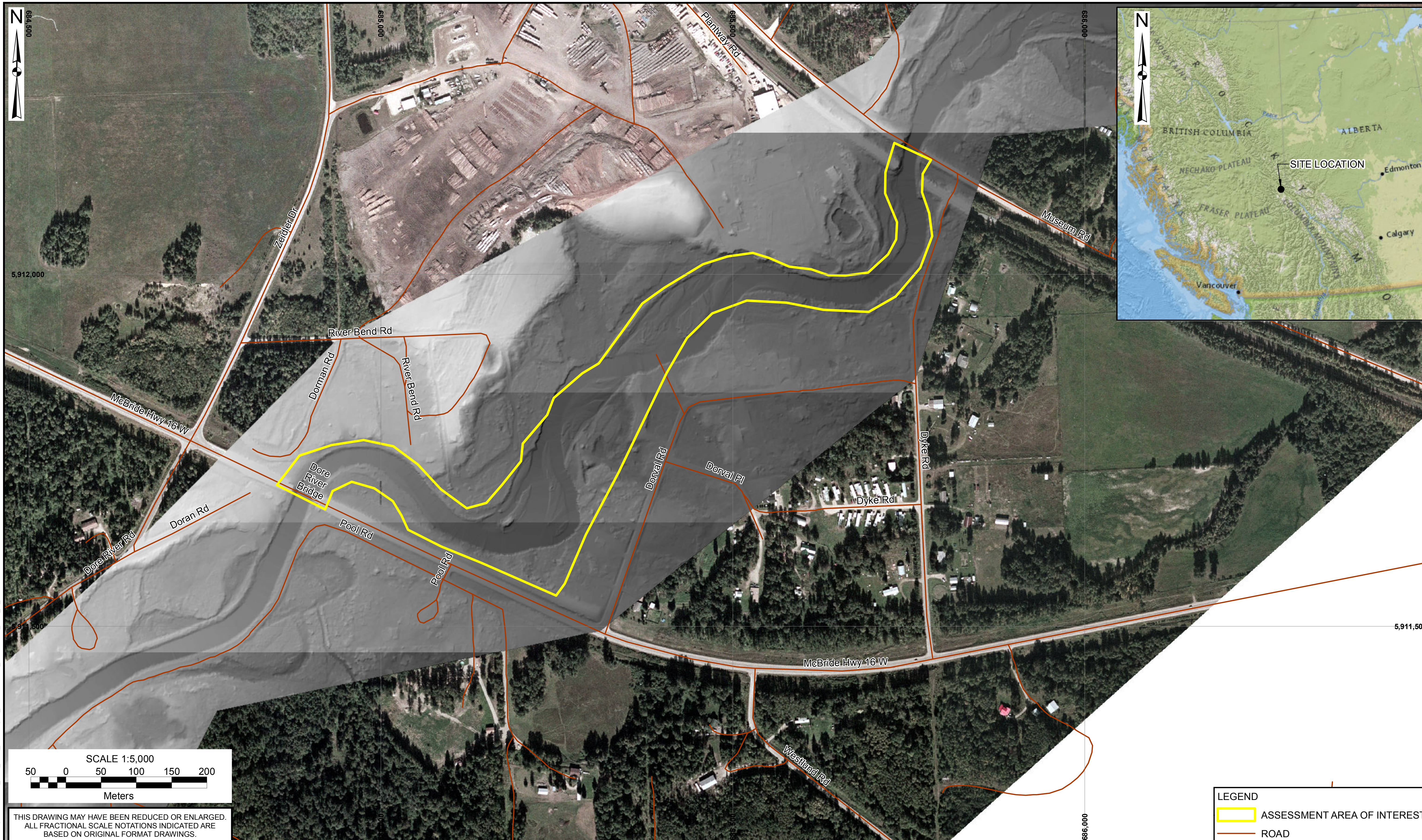
PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: DORE RIVER WATERSHED

PROJECT No.: 1572-006

DWG No: 01

X:\Projects\1572\006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\01_Dore_River_Watershed.mxd



X:\Projects\1572\006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\02_Assessment_Area_of_Interest.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
4. COORDINATE SYSTEM IS NAD83 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:5,000
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	KH
APPROVED:	-

CLIENT: MCELHANNEY LTD.

BGC

PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: ASSESSMENT AREA OF INTEREST

PROJECT No.:	DWG No:
1572-006	02

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA FROM GOOGLE EARTH DATED 2019, AND FROM ESRI WORLD IMAGERY LAYER.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:2,500
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	KH
APPROVED:	HW

CLIENT: MCELHANNEY LTD.

BGC

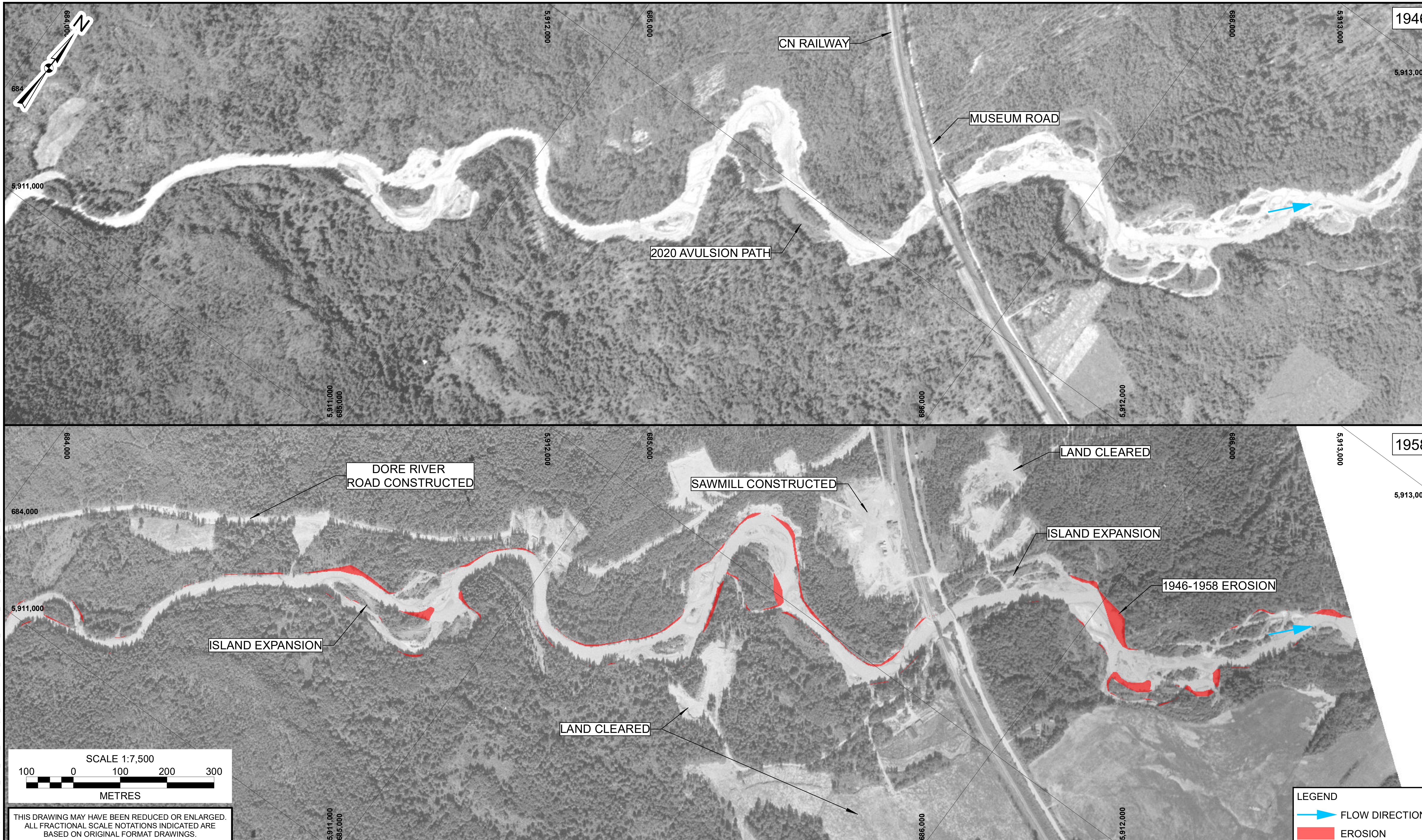
PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: DORE RIVER FLOOPLAIN

PROJECT No.: 1572006

DWG No: 03

X:\Projects\1572\006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\03_Dore_River_Floodplain_in_the_AOI.mxd



X:\Projects\1572006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\04_Historical_Channel_Changes_at_Dore_River_1946_1958.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA PROVIDED BY THE GOVERNMENT OF BRITISH COLUMBIA, DATED 1946 AND 1958.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:7,500
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	SD
APPROVED:	HW

CLIENT: MCELHANNEY LTD.

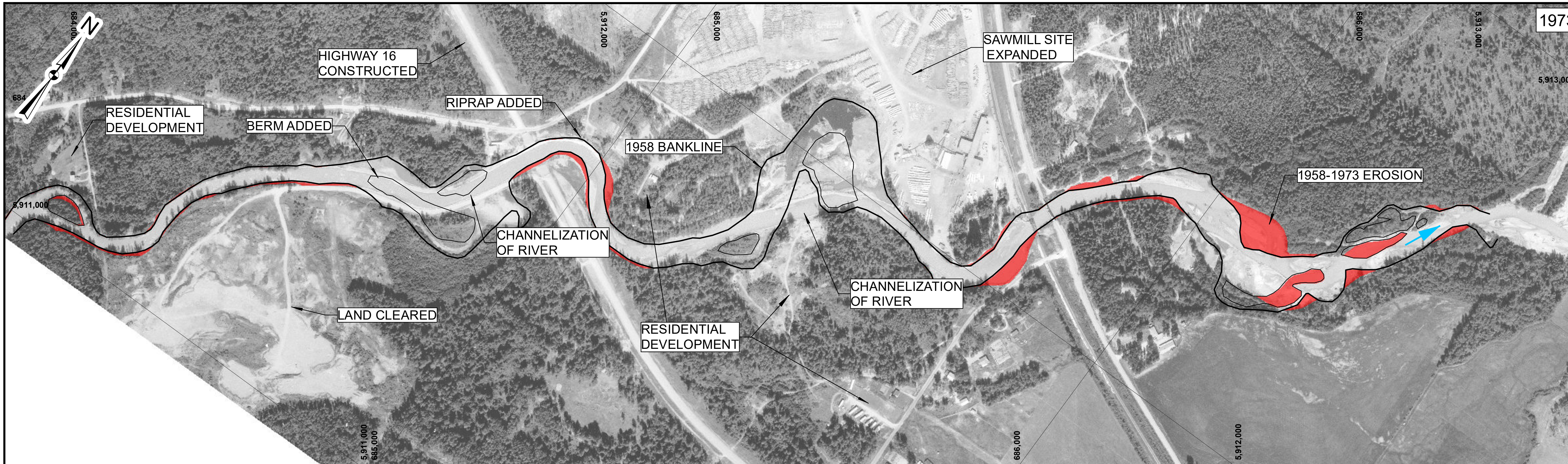
BGC

PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: HISTORICAL CHANNEL CHANGES AT DORE RIVER (1946 - 1958)

PROJECT No.: 1572006

DWG No: 04



X:\Projects\1572\006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\05_Historical_Channel_Changes_at_Dore_River_1958_1976.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA PROVIDED BY THE GOVERNMENT OF BRITISH COLUMBIA, DATED 1973 AND 1976.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:7,500
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	SD
APPROVED:	HW

CLIENT: MCELHANNEY LTD.

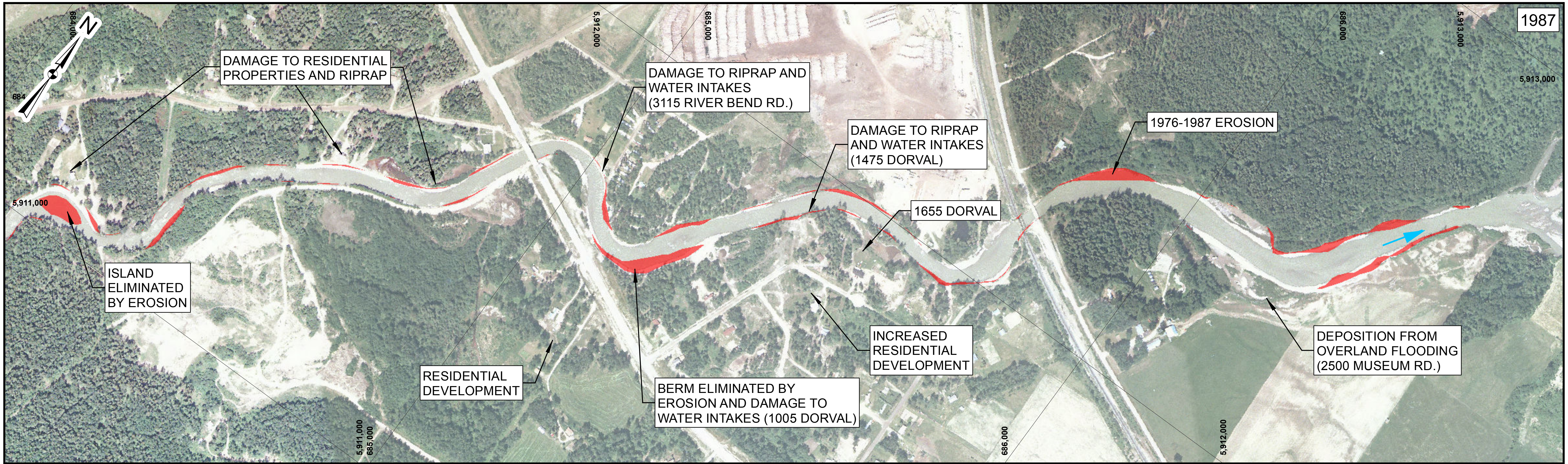
BGC

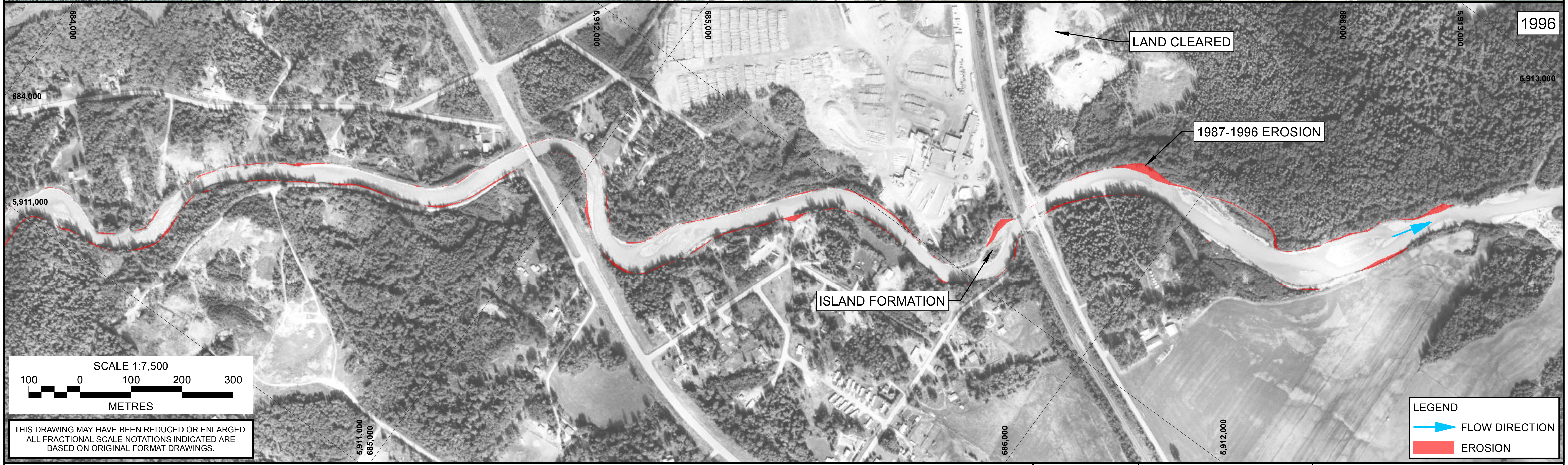
PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: HISTORICAL CHANNEL CHANGES AT DORE RIVER (1958 - 1976)

PROJECT No.: 1572006

DWG No: 05





NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA PROVIDED BY THE GOVERNMENT OF BRITISH COLUMBIA, DATED 1987 AND 1996.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:7,500
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	SD
APPROVED:	HW

CLIENT: MCELHANNEY LTD.

BGC

PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: HISTORICAL CHANNEL CHANGES AT DORE RIVER (1976 - 1996)

PROJECT No.: 1572006

DWG No: 06

X:\Projects\1572006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\06_Historical_Channel_Changes_at_Dore_River_1976_1996.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA PROVIDED BY THE GOVERNMENT OF BRITISH COLUMBIA DATED 2006, AND FROM GOOGLE EARTH DATED 2019.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:7,500
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	SD
APPROVED:	HW

CLIENT: MCELHANNEY LTD.

BGC

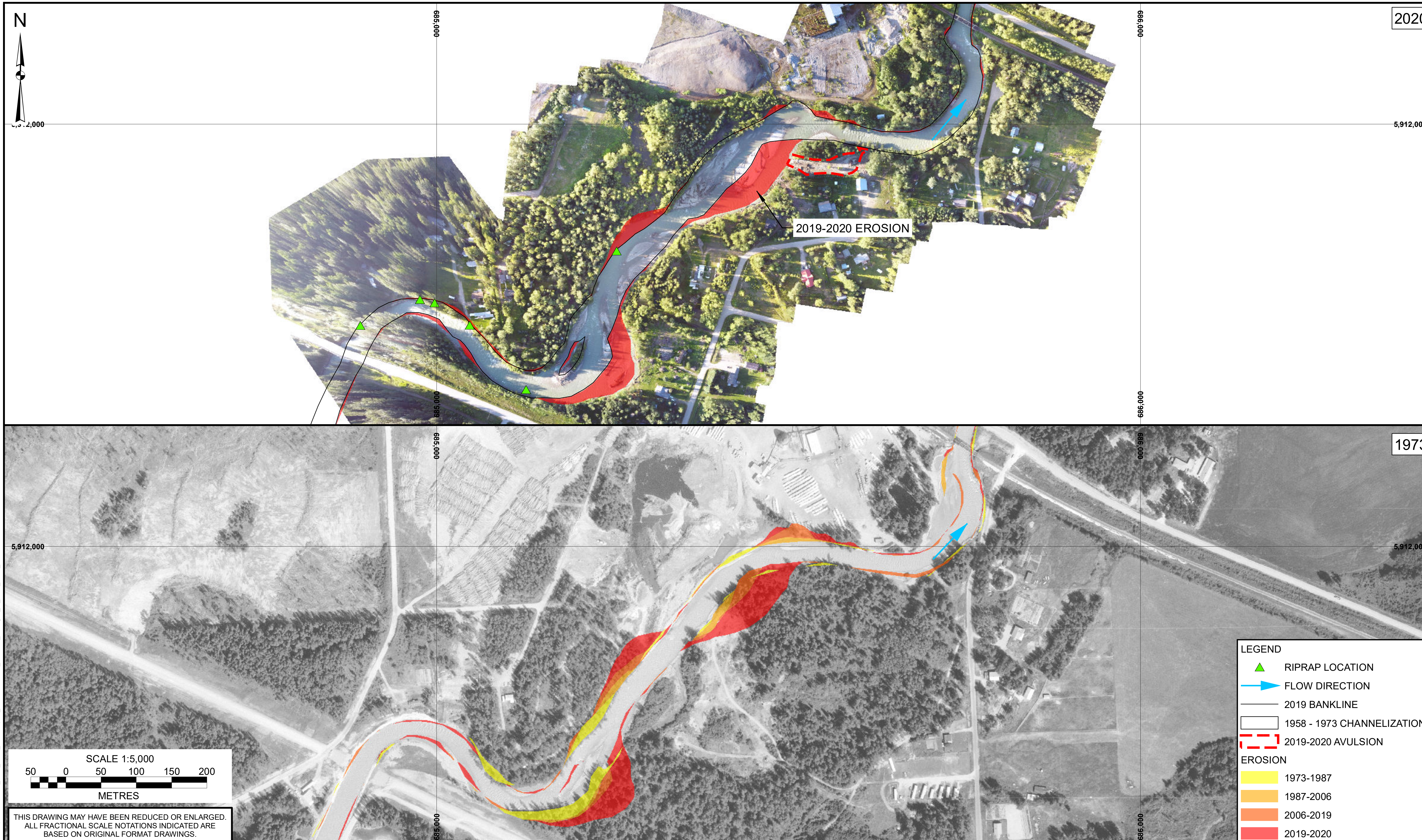
PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: HISTORICAL CHANNEL CHANGES AT DORE RIVER (1996 - 2019)

PROJECT No.: 1572006

DWG No: 07

X:\Projects\1572\006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\07_Historical_Channel_Changes_at_Dore_River_1996_2019.mxd



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA PROVIDED BY THE GOVERNMENT OF BRITISH COLUMBIA DATED 1973, AND FROM A DRONE SURVEY DATED 2020.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: 1:5,000	CLIENT: MCELHANNEY LTD.	PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT	
DATE: MAR 2021		TITLE: CHANNEL CHANGES AT DORE RIVER (1973 - 2020)	
DRAWN: JVC	BGC		
REVIEW: SD		PROJECT No.: 1572006	DWG No: 08
APPROVED: HW			

X:\Projects\1572006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\08_Channel_Changes_at_Dore_River_2020.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DORE RIVER GEOMORPHIC ASSESSMENT", AND DATED MARCH 2021.
3. IMAGERY DATA FROM GOOGLE EARTH DATED 2019.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:2,500
DATE:	MAR 2021
DRAWN:	JVC
REVIEW:	SD
APPROVED:	HW

CLIENT: MCELHANNEY LTD.

BGC

PROJECT: DORE RIVER GEOMORPHIC ASSESSMENT

TITLE: MODELLED EROSION DURING A 200-YEAR FLOOD EVENT AT DORE RIVER

PROJECT No.: 1572006

DWG No: 09

X:\Projects\1572006\GIS\Production\Report\20201103_Dore_River_Geomorphic_Assessment\09_Modelled_Erosion_at_Dore_River.mxd

APPENDIX D – WSC GAUGE DATA USERS GUIDE

Appendix D: WSC Gauge Data Users Guide

An active and maintained river gauge already exists 2 km upstream of the site. The Dore River WSC gauge (Dore River near McBride 08KA001) provides real time water level and flow data for the Dore River. Anyone can access the real time gauge data via: https://wateroffice.ec.gc.ca/search/real_time_e.html.

The user will then be directed to the display show in Figure A. Access the gauge by entering that station number for the Dore Gauge (08KA001).

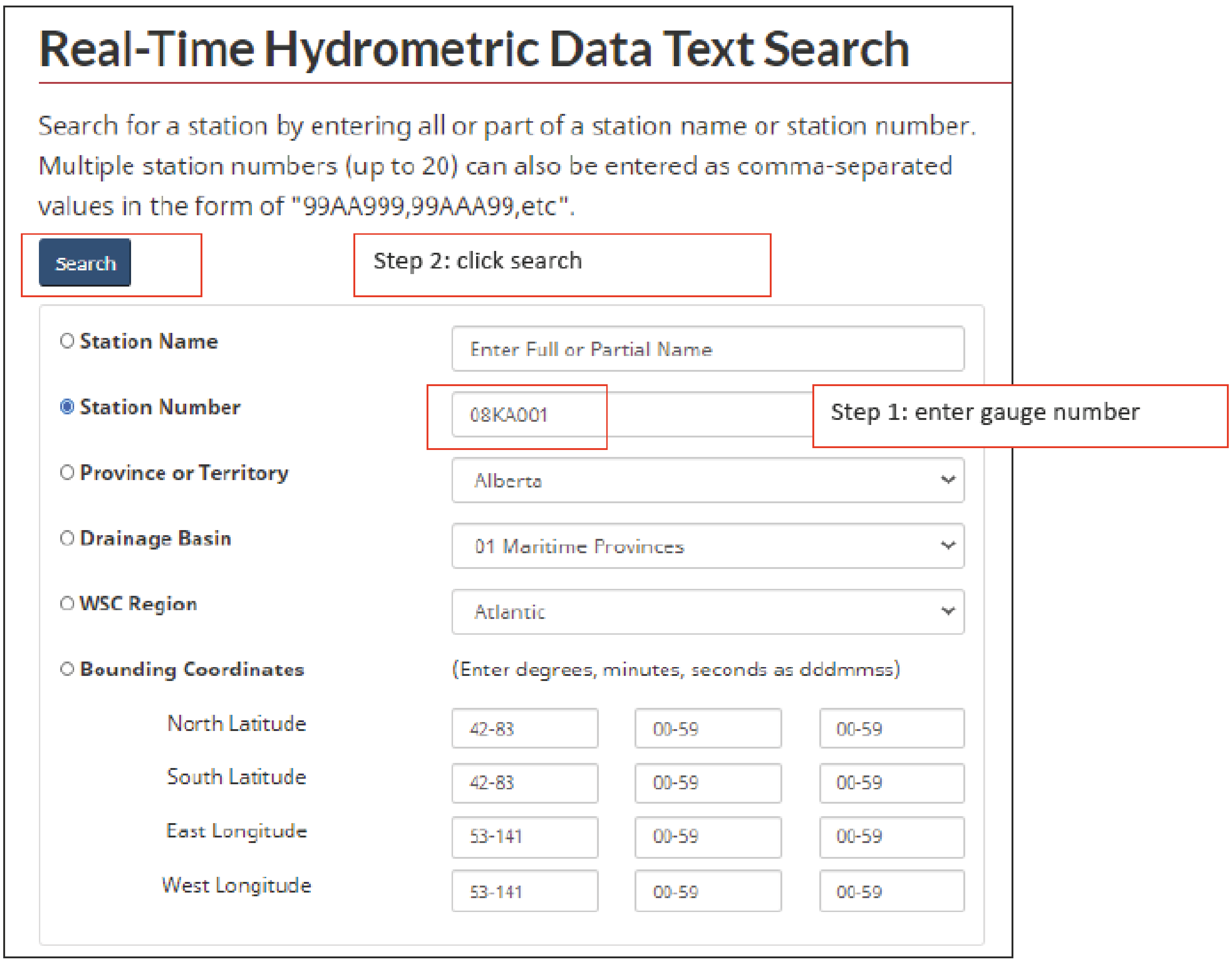


Figure A – WSC gauge search display screen

After clicking “search”, the user will then be brought to the screen shown in Figure B.

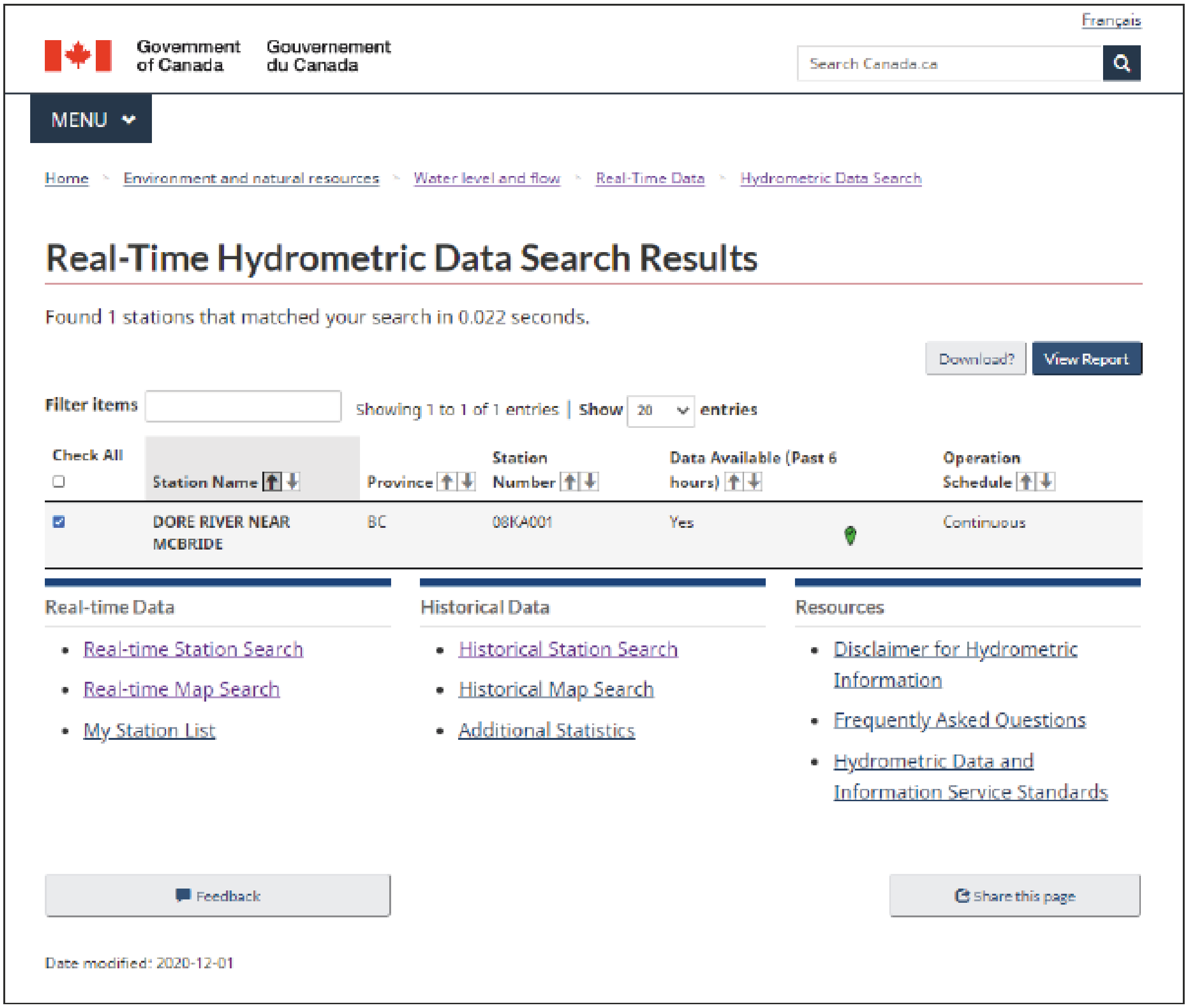


Figure B – WSC gauge search results page

Clicking the "View Report" button will bring the user to the screen shown in Figure C. The graph will display the water level and discharge for the past week. There is a delay of an hour (or more depending on the station) with the gauge reporting the most current flow data.

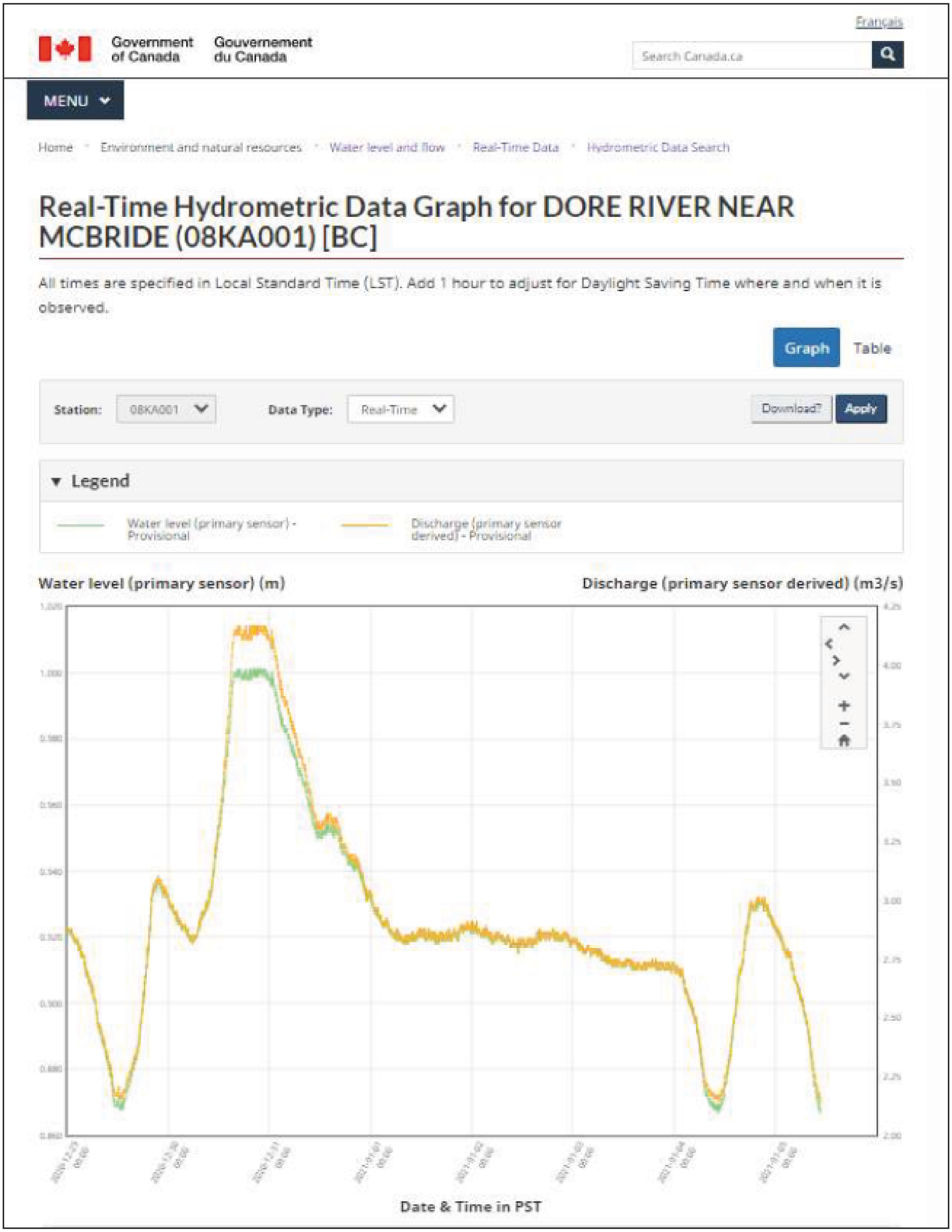


Figure C – Real time WSC gauge data display

APPENDIX E – DORE RIVER PROPOSED RIPRAP EXTENTS

REGIONAL DISTRICT of Fraser-Fort George

Dore River Area of Interest Map Showing Proposed Riprap Extents

Riprap Extents
Civic Address
Streets
Approximate Property Boundaries
July 26, 2020 Drone Photo
Bing Satellite

Riprap Lengths and Volumes

A: Length 350 m Volume 1750 m3
B: Length 210 m Volume 1050 m3
C: Length 510 m Volume 2550 m3
D: Length 130 m Volume 650 m3

McElhanney

0 25 50 m

Scale=1:2,000

Projection: BC Albers
Datum: NAD83

Project No.	Date
2341-21107-00	January 8, 2021

Figure 1-1

Dore River Area of Interest Map Showing Proposed Riprap Extents