REPORT

Ministry of Transportation and Infrastructure

Daly Bridge 06489 Replacement 100% Hydrotechnical Design

MARCH 2023

EXECUTIVE SUMMARY

The **Ministry of Transportation and Infrastructure** (MoTI) engaged **Associated Engineering (B.C.) Ltd.** (Associated) to provide hydrotechnical engineering, tendering, and construction services for the Daly Bridge 06489 (the bridge) Replacement project. The bridge is located east of the Village of Lumby on Creighton Valley Road. The purpose of this report is to outline the hydrotechnical analysis completed in support of the 100% design. A summary of the hydrotechnical design parameters and recommendations is provided in the table below. The hydrotechnical design includes riprap scour and erosion protection, large wood features, and live staking.

Hydrotechnical Design Parameters	Design Recommendations
Hydrological Design Criterion	200-Year Instantaneous
Flow without Climate Change Adaptation	20.4 m^3/s
Recommended Flow Increase for Climate Change Adaptation	+ 10%
Design Flow	22.5 m^3/s
Bridge Opening Minimum Bottom Width	5 m
Bank Side Slopes	1.5H (min.) : 1V
Design Flow Water Elevation	503.75 m
Design Flow Water Depth	1.13 m
Minimum Freeboard	1.0 m
Minimum Soffit (Low Chord) Elevation	504.75 m
Average Channel Velocity	1.4 m/s
Design Velocity at Daly Bridge	2.97 m/s
Estimated Scour Depth, and Minimum Riprap Toe Key Depth	0.8 m
Recommended Riprap Class for Erosion and Scour Mitigation at Daly Bridge	100 kg
Recommended Bed Elevation to Trigger Channel Dredging	503.62 m
Large Wood Features: **Tree Trunk (with Root Wad Still Intact) Diameter** **Tree Trunk (with Root Wad Still Intact) Length** **Ballast Boulder Diameter**	 0.5 m (min.) 2.5 m (min.) 0.75 m (min.)

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1 INTRODUCTION

The **Ministry of Transportation and Infrastructure** (MoTI) engaged **Associated Engineering (B.C.) Ltd.** (Associated) to provide hydrotechnical engineering, tendering, and construction services for the Daly Bridge 06489 (the bridge) Replacement project. The bridge is located east of the Village of Lumby on Creighton Valley Road. The purpose of this report is to outline the hydrotechnical analysis completed in support of the 100% design.

2 DESIGN FLOW CRITERION AND DESIGN EXCEPTION

An August 2021 traffic study determined that the annual average daily traffic (ADDT) on Creighton Valley Road exceeds 400 vehicles per day. Based on the traffic count, Creighton Valley Road is as a Collector Road and the hydrological design criterion (MoTI 2019) for the site is the 200-year return period peak instantaneous flow.

Designing the bridge for the 200-year peak instantaneous flow will also comply with the requirements of the *Water Sustainability Regulation* (Province of BC 2020), which requires bridges be designed to convey the 200-year return period maximum daily flow.

The bridge design team requested a structural design exception, pertaining to BC Supplement to S6-14 Clause 1.9.7.1, to lower the bridge soffit from 1.5 m to 1 m above the 200-year water level. This hydrotechnical report has been prepared based on the design exception from the MoTI.

The *Water Sustainability Regulation* (Province of BC 2020) requires temporary construction period diversions through the bridge worksite be designed to convey the 10-year maximum daily flow. Associated determined the 10-year maximum daily flow for the least risk instream work window for Creighton Creek (August 7 to October 21) and the analysis is summarized in **Section 5**.

3 SITE AND WATERSHED DESCRIPTIONS

3.1 Watershed

The bridge watershed is located within the Okanagan Highland (No. 23) and Northern Columbia Mountains (No.14) Hydrological Zones (Coulson and Obedkoff 1998). Most of the watershed is located in Zone No. 23 and the northern edge extends into Zone No. 14. The Creighton Creek watershed area is 102.6 km^2 at the bridge (**Figure 3-1**). Elevations in the watershed vary from approximately 502 m at the bridge to 1,810 m in the watershed uplands. The upland areas of the watershed are forested, and the lowlands are primarily flat, agricultural land.

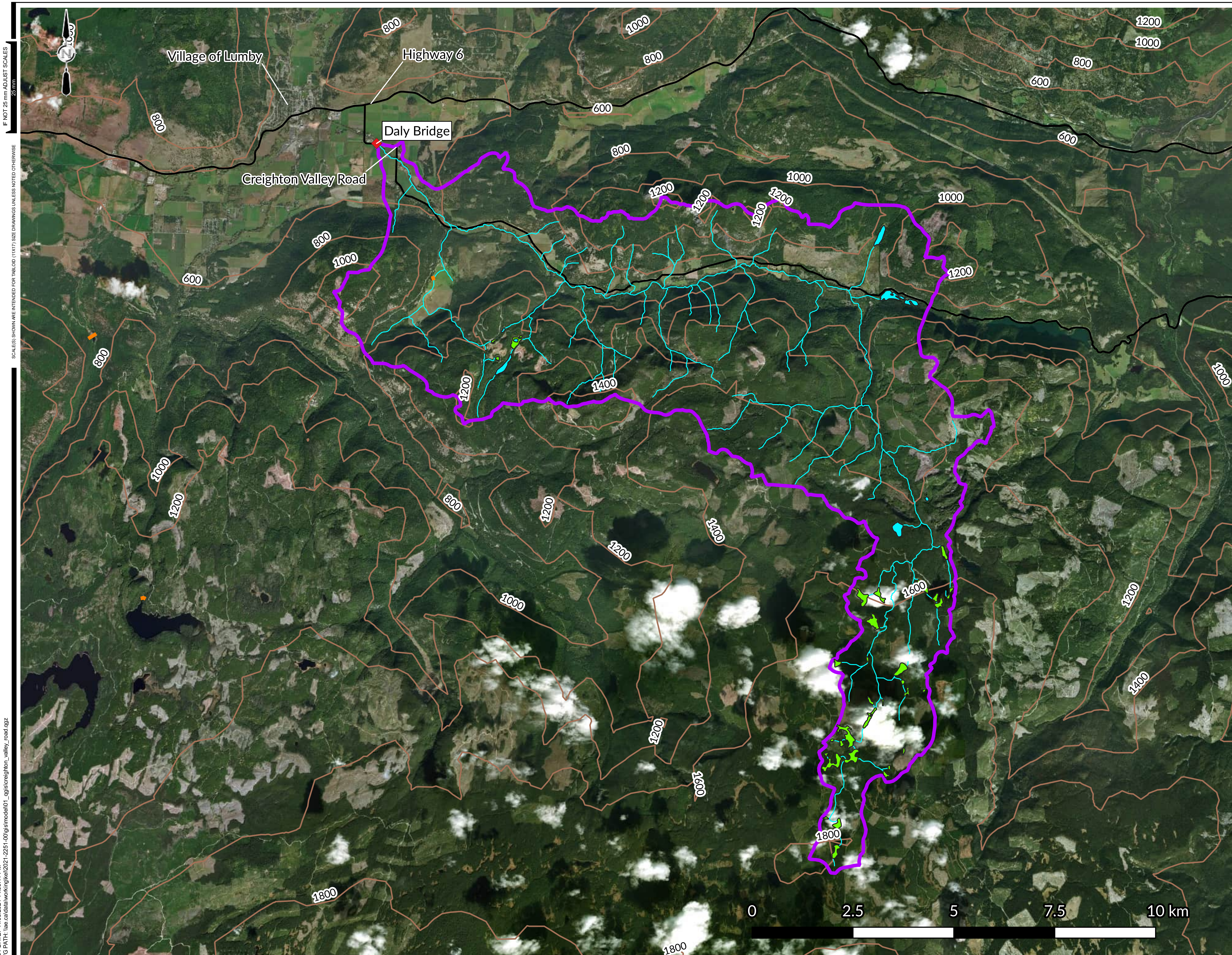
There is a single dam (Higgins Creeks #2) in the watershed. The structure is a low consequence dam, and the embankment height is approximately 1 m. Wetlands and small lakes are present in the upland areas of the watershed (**Figure 3-1**), which can attenuate downstream flows. There are no notable lakes or wetlands in the lowland region around the bridge.

3.2 Site

The existing bridge is a single span structure located approximately 1.2 km south of the intersection of Highway 6 and Creighton Valley Road. The bridge is located on an alluvial fan. Alluvial fans are often associated with lateral instability and channel avulsions (APEGBC 2017). Based on anecdotal information from the MoTI, there has been historical channel aggradation and localized overland flooding around the bridge. However, Associated is not aware of any lateral channel instability issues.

The LiDAR data provided by the MoTI covers the channel and floodplain extending approximately 3 km upstream and 1.5 km downstream of the bridge (**Figure 3-2**). The LiDAR data was supplemented with a detailed topographic survey of the channel extending approximately 150 m upstream and downstream of the bridge. The topographic data was used to develop a hydraulic model which is discussed further in **Section 6**.

Associated completed an initial site visit on May 19, 2021, to observe the bridge and channel characteristics. During this site visit a local resident reported that their property upstream of the bridge is frequently flooded during freshet.



Associated Engineering

LEGEND

- Watercourse
- Road
- 20 m Contours
- Dam
- Daly Bridge
- Daly Bridge Catchment Area
- Lakes
- Wetlands

British Columbia — Ministry of Transportation and Infrastructure

FIGURE 3-1

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

DALY BRIDGE WATERSHED

AE PROJECT No.	2021-2251-00
SCALE	1 : 90,000
APPROVED	G. CAHILL
DATE	2023MAR
REV	A
DESCRIPTION	ISSUED FOR REPORT

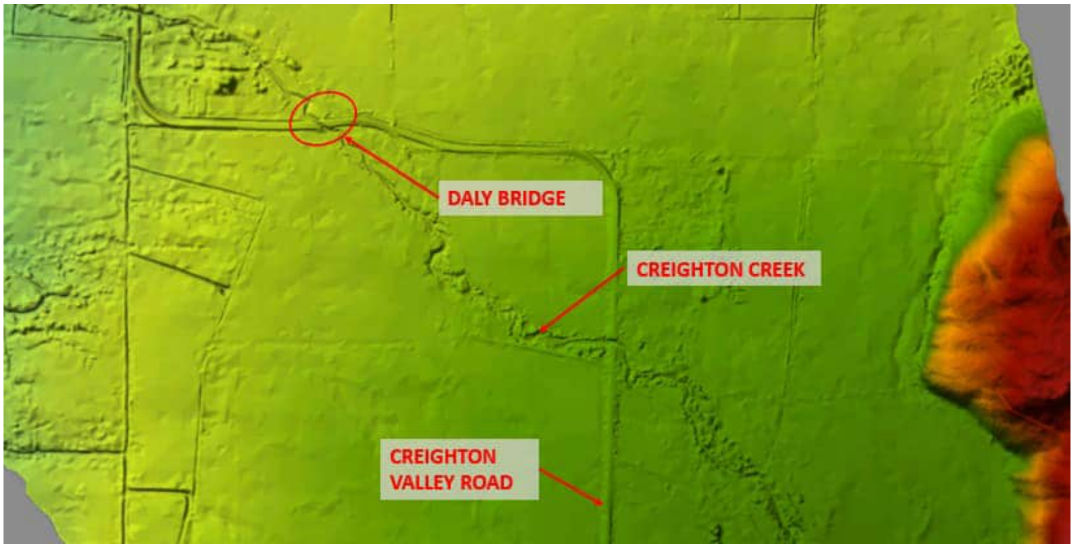


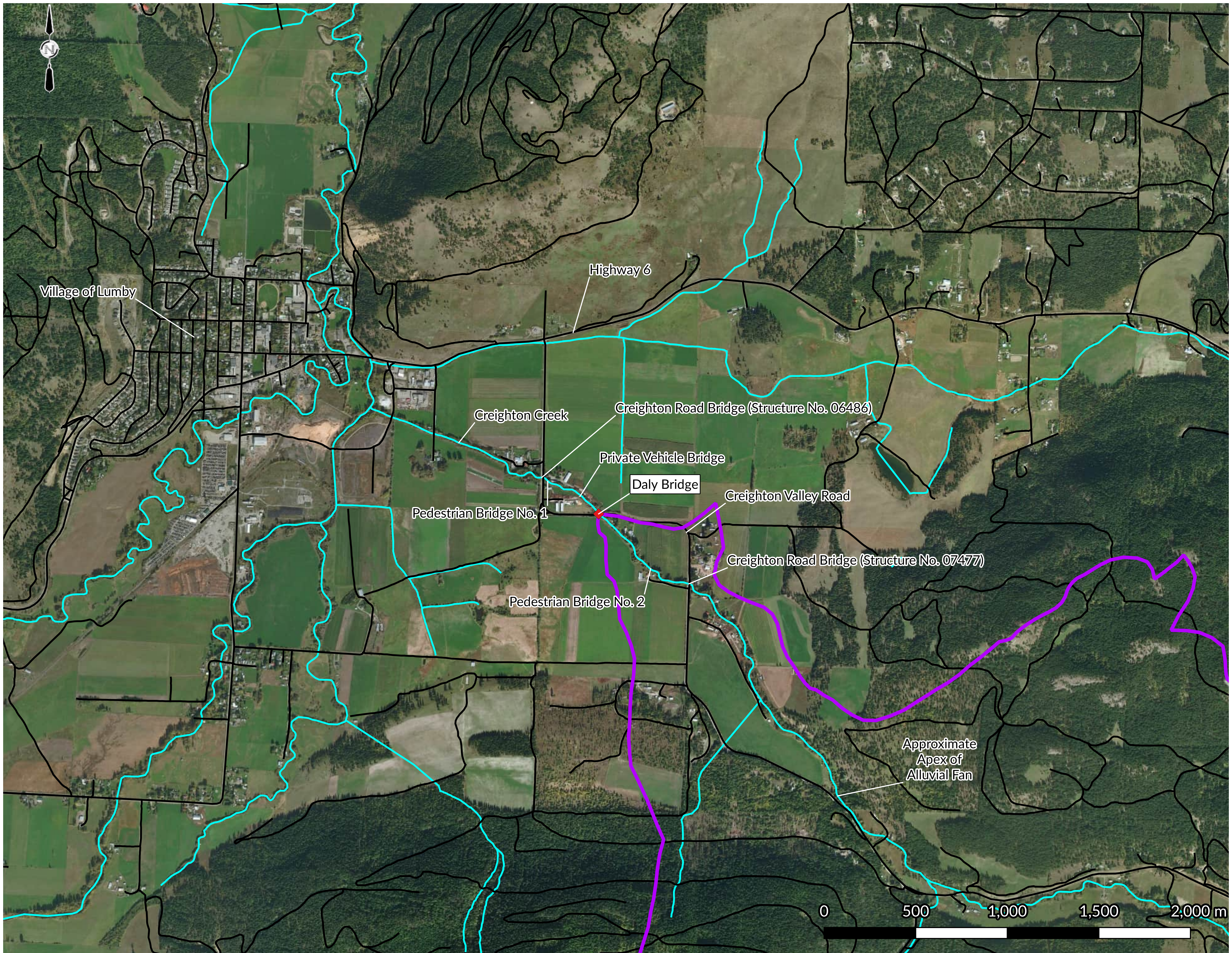
Figure 3-2
Creighton Creek Combined Topographic/Bathymetric Survey and LiDAR Surface

Two additional MoTI bridges are located on Creighton Valley Road upstream and downstream of the bridge (**Figure 3-3**). A private vehicle bridge is also visible in aerial imagery approximately 150 m downstream from Daly Bridge. Associated conducted a second site visit on June 16, 2021, to observe the Creighton Creek channel characteristics between the upstream and downstream MoTI bridges and to examine the geometry of the nearby bridge openings. During the site visit Associated identified two additional pedestrian bridges that were not visible in the aerial imagery. The location of these bridges is shown in **Figure 3-3**. The approximate height of the bridge soffits above the channel bed is summarized in **Table 3-1**. Select site photos are provided in **Appendix A**.

Table 3-1
Bridge Geometry (Field Measurements)

Bridge Name[1]	Approximate Height of Bridge Soffit above Channel Bed (m)
Creighton Road Bridge (Structure No. 06486)	0.65
Pedestrian Bridge No. 1	> 0.9
Private Vehicle Bridge	1.0
Daly Bridge (Structure No. 06489)	0.7
Pedestrian Bridge No. 2	0.6
Creighton Road Bridge (Structure No. 07477)	0.4

[1]Bridges in **Table 3-1** are listed in order from downstream to upstream.



IF NOT 25 mm ADJUST SCALES
25 mm

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

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LEGEND

- Watercourse
- Road
- Daly Bridge
- Watershed Boundary

FIGURE 3-3

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

PROJECT LOCATION

AE PROJECT No.	2021-2251-00
SCALE	1 : 20,000
APPROVED	G. CAHILL
DATE	2023MAR
REV	A
DESCRIPTION	ISSUED FOR REPORT

3.3 Fluvial Geomorphology

3.3.1 Channel Characteristics

Associated examined the characteristics of Creighton Creek between MoTI Bridge Structure No 07477 and MoTI Bridge Structure No. 06486 during the June 16, 2021, site visit. The channel width generally varies from 4 m to 5 m and the bed material is primarily sand and gravel, with some cobble-sized material (**Figure 3-4**). The channel generally has riffle-pool morphology.

Figure 3-4
Creighton Creek Sand and Gravel Bed Material

Channel Profile

The Creighton Creek headwaters originate in mountainous terrain and the mainstem channel is confined by the mountain walls down to an alluvial fan. The alluvial fan apex is located approximately 2 km upstream of the bridge. Downstream of the alluvial fan apex, the floodplain is approximately 3 km wide across the alluvial fan. The alluvial fan has formed from deposition in this flatter, lowland area (FLNRO 2005). **Figure 3-5** shows the general channel profile along the modelled extents. The profile originates approximately 3 km upstream of the bridge and extends approximately 1.5 km downstream from the bridge to the confluence with Bessette Creek. The channel profile has a uniform slope of approximately 1% on the alluvial fan.

Morphology

Associated observed a riffle-pool morphology during the June 16, 2021, site visit. Relatively deep, slow-moving pools are separated by faster flowing riffles. The riffles are sediment accumulations that form local high points, with steeper gradients that extend diagonally across the channel to the upstream end of a bar. Bars are an area of sediment storage on riffle pool channels (FLNRO 2010).

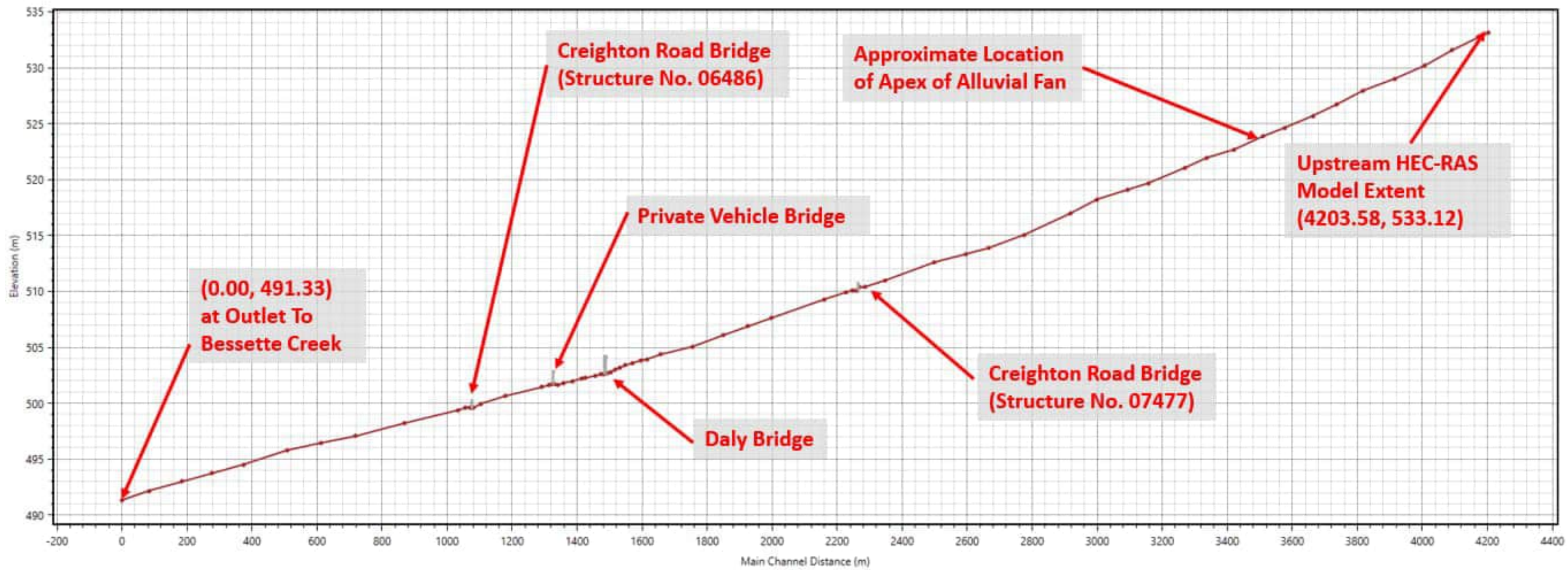


Figure 3-5
Creighton Creek Channel Profile

Creek channels with a riffle pool morphology are generally stable but dynamic. When sediment supply increases, the bed material becomes finer, and the channel bars can expand, become unstable, and migrate toward the center of the channel. The sediment is transferred from the pools to the riffles during periods of high sediment supply. When sediment supply decreases the channel bed material becomes coarser. The bridge bed material is composed primarily of finer gravel and sand which is a characteristic of high sediment supply.

The bedload in creeks with riffle-pool morphologies is generally only mobilized during high stage events at or greater than the bank full discharge. The bed material is generally first mobilized by fast moving riffles and is deposited at the next downstream riffle. Changes in sediment supply and discharge can cause either vertical shifts in the channel bed or lateral shifts of the banks in rifle-pool channels.

Sediment

Alluvial fans are frequently associated with aggradation problems at highway crossings (FHWA 2012). Aggradation can reduce the bridge opening area and widen the channel. These changes increase the risk that the channel will undermine piers and abutments and can increase the likelihood of channel avulsions (FHWA 2009). Significant aggradation has occurred at Creighton Road Bridge Structure 07477 upstream of the bridge. Section A on Creighton Valley Bridge General Arrangement Drawing No. 7477-5 shows that the bridge low chord was designed approximately 1.8 m above the channel bed in 1997. The bridge soffit was only 0.4 m above the channel bottom at the time of the June 16, 2021, site visit which indicates that more than 1 m of sediment deposition has occurred at this bridge since it was constructed (**Figure 3-6**).

Based on this aggradation depth upstream, it is assumed that approximately 0.05 m of sediment could accumulate annually. This is a frequency of about 0.5 m every 10 years. Therefore, it is reasonable to assume that dredging at the bridge will be required approximately once every 10 years to maintain the waterway opening through the bridge.

Riparian Corridor and Lateral Stability

Riparian vegetation is present along the channel banks between the MoTI bridges (**Figure 3-7**). The riparian vegetation enhances the bank strength and reduces lateral channel movement (FLNRO 2010).

The Regional District of North Okanagan (RDNO) online mapping provides 2007 and 2016 aerial images of Creighton Creek. The channel appears laterally stable during this period. There are no signs of disturbance to the vegetation at the channel bends at locations A, B, and C in the aerial imagery (**Figure 3-8** and **Figure 3-9**). Furthermore, there are no signs of oxbow lakes, sloughs, abandoned channels, disappearing streams, or sudden changes in channel direction, which would demonstrate the occurrence of historic lateral instability (FLNRO 2005).

Based on the channel planform Creighton Creek can be classified as a wandering channel. Wandering channels are generally characterized as possessing moderate channel gradient, stability, and sediment supply (FLNRO 2010). Although, the channel shows no sign of historical lateral instability continued aggradation in the vicinity of the bridge will increase the likelihood of a sudden channel realignment from an avulsion.

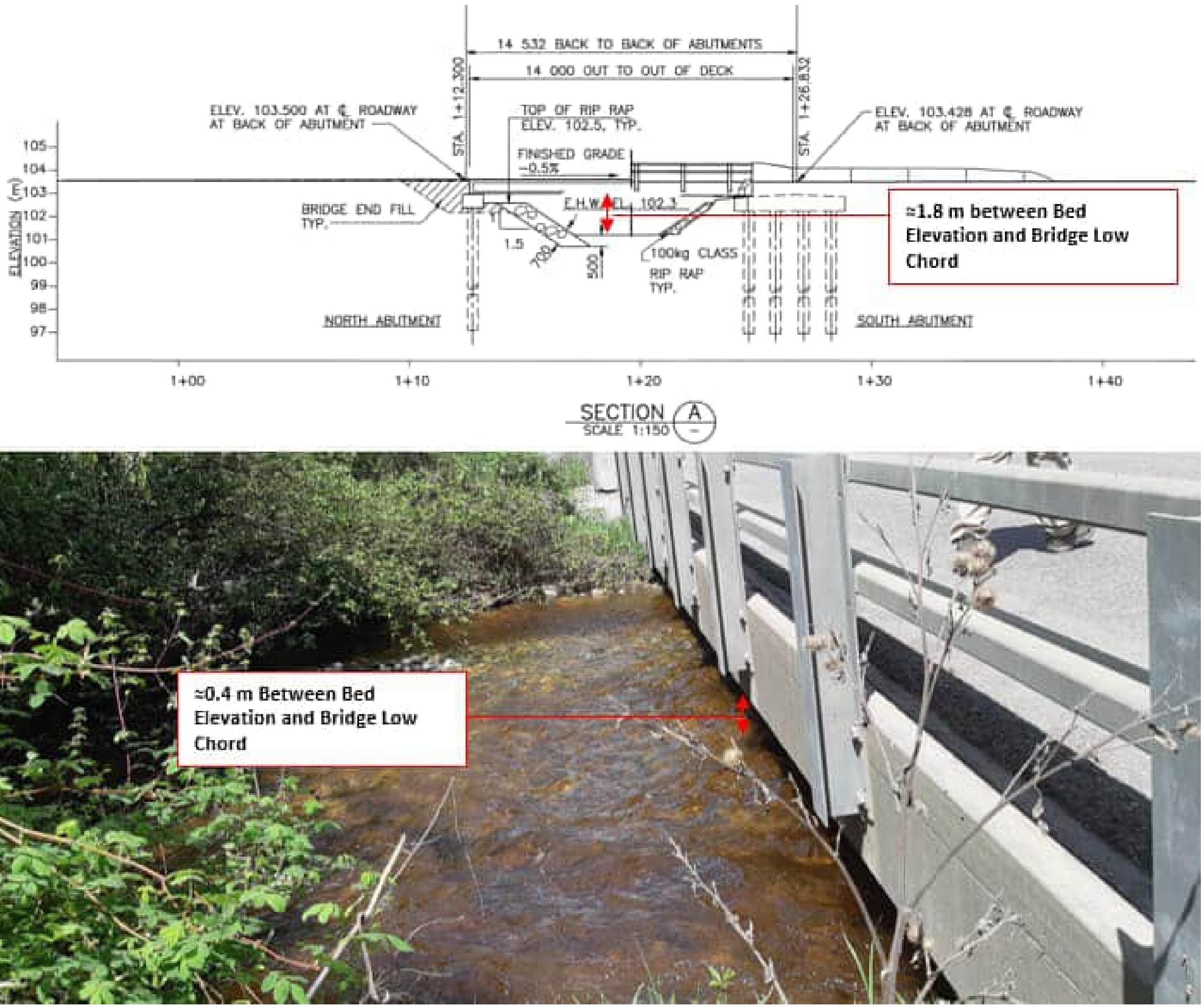


Figure 3-6

Bridge Aggradation at Creighton Bridge 07477. The Bridge has Aggraded by More than 1 m Between 1997 and the June 2021 Site Visit

Figure 3-7
Creighton Creek Riparian Corridor

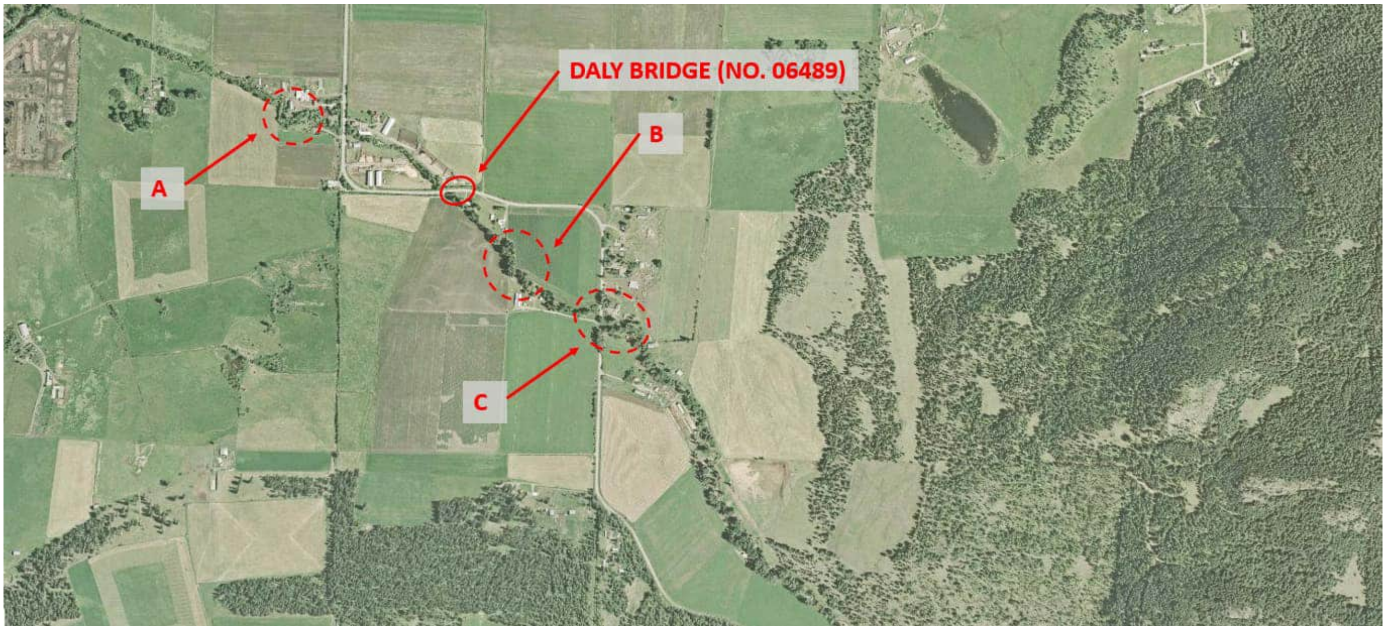


Figure 3-8

2007 Creighton Creek Aerial Imagery. Locations A, B, and C are Bends in Creighton Creek that Were Used as Specific Points of Comparison Against the 2016 Aerial Imagery. (Courtesy of the RDNO Interactive Mapping Application)

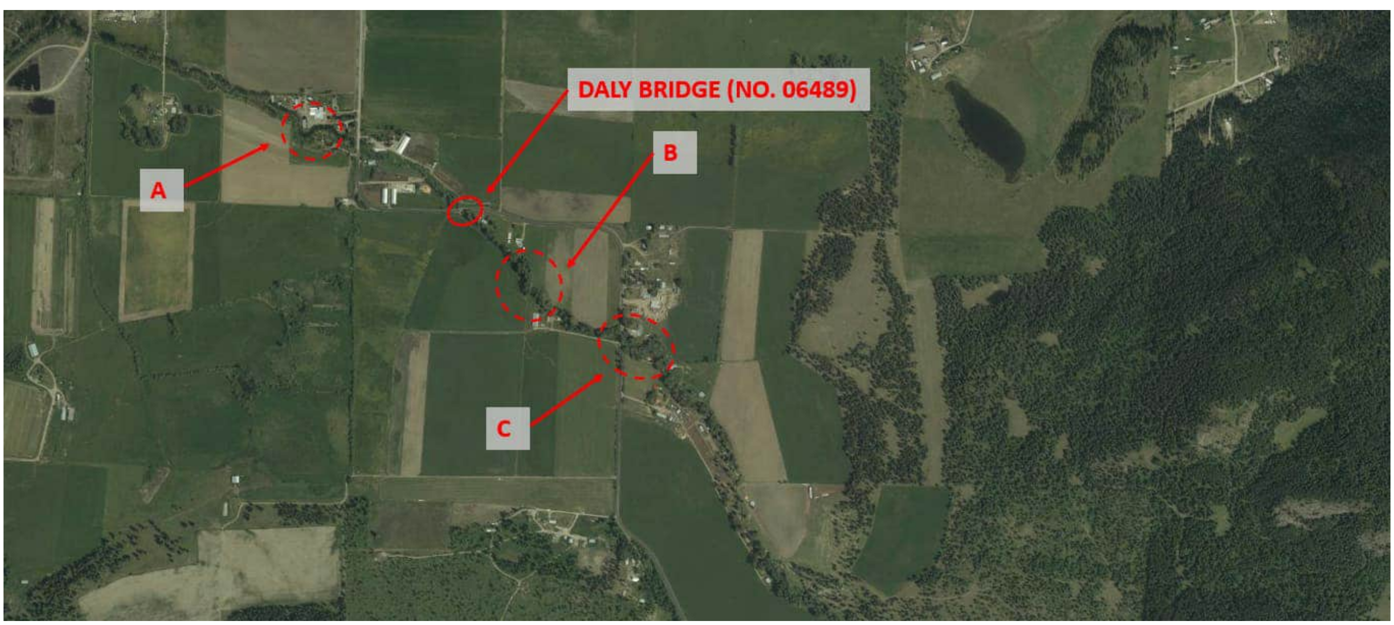


Figure 3-9

2016 Creighton Creek Aerial Imagery. Locations A, B, and C are Bends in Creighton Creek That Were used as Specific Points of Comparison Against the 2007 Aerial Imagery. (Courtesy of the RDNO Interactive Mapping Application)

Large Wood

Large wood was observed in the channel and along the banks of Creighton Creek (**Figure 3-10**). The large wood was primarily composed of complexes of small to moderately large branches rather than single large logs or fallen trees. Large wood is an important component of aquatic ecosystems and can alter the channel flow path and velocity. Large wood can increase sedimentation and significantly alter the rate of bedload mobilization, channel width, and fish habitats (FLNRO 2010). The channel morphology and width were consistent along Creighton Creek between the upstream and downstream MoTI bridge structures (No. 07477 and No. 06486), which can be partially attributed to the lack of large wood along reach. Future tree blowdown, mortality, or bank erosion could lead to increased quantities of large wood in the channel that could generate more variable channel morphology in the future.

Figure 3-10
Small Woody Debris Deposited Along the Bank of Creighton Creek

3.3.2 Primary Fluvial Geomorphological Processes

Debris floods, debris flows, and clearwater floods are the primary hydrogeomorphic processes that form alluvial fans (FLNRO 2009). Debris floods and flows are geomorphological events which are primarily categorized based on how much sediment movement there is in an event. Debris floods have less sediment compared to debris flows. The events can have devastating consequences, as their peak discharges can be 2 to 50 times greater than those of clearwater floods.

The Melton Ratio is a watershed parameter used to identify watersheds prone to debris floods and flows (Wilford et al. 2004). The ratio is commonly defined as watershed relief divided by the square root of the watershed area (Melton, 1957).

$$\boldsymbol{Melton\ Ratio} = Watershed\ Relief \div \sqrt{Watershed\ Area}$$

Associated estimated the debris flood and flow using a modified method described by Wilford et al. (2004). The method can be used to identify debris flood and flow potential using Melton Ratio and watershed length. Associated obtained an estimate of the watershed area, relief, and length from digital mapping. Based on the analysis, the bridge watershed upstream of the bridge crossing is unlikely to experience debris floods or flows. Therefore, the alluvial fan was likely formed and will continue to be formed by clearwater floods. A summary of the analysis is provided in **Table 3-2**.

Table 3-2
Daly Bridge Watershed Melton Ratio

Parameter	Value
Watershed Area (km^2)	102.6
Relief (km)	1.3
Watershed Straight-line Planimetric Length (km)	26.2
Melton Ratio (km/km)	0.13 (unlikely to experience debris flow or debris flood)

3.4 Fluvial Geomorphology Summary and Recommended Countermeasures

Progressive sediment deposition is the primary geomorphic hazard at the bridge. Possible countermeasure options include (FHWA 2009 & FHWA 2012):

- **Debris basin:** A debris basin consists of a pool and a flow barrier. The barrier slows the flow which reduces the channel carrying capacity and promotes deposition within the pool.
- **Channelization**: Channelization options include dredging or designing a channel cut-off to increase the hydraulic capacity in the vicinity of the bridge. Furthermore, flow control structures can be constructed to maintain the channel width.
- **Maintenance**: Maintenance programs can involve regular channel surveys to track aggradation at the bridge to determine when dredging is required.
- **Bridge Design**: Bridge designs or modifications to accommodate aggradation can include widening the bridge or raising the deck to maintain the flow area.

Associated recommends the bridge design and maintenance countermeasure options to mitigate aggradation. Debris basins can effectively control aggradation on alluvial fans. However, to mitigate aggradation at the bridge a large debris basin would need to be constructed at the apex of the alluvial fan where Creighton Creek emerges from the confines of the mountain slopes. This solution would have large capital and operating costs. Channelization is generally unable to sufficiently increase the sediment carrying capacity to alleviate aggradation issues and therefore this alternative is not recommended.

Channel alterations at the bridge should be constructed to maintain a 5 m base width. Aggradation should be monitored annually, and dredging could be required in the future. A dredging plan will be required along with regulatory approval to complete instream work.

4 CLIMATE CHANGE CONSIDERATIONS

4.1 Pacific Climate Impacts Consortium: Plan2Adapt

Associated reviewed climate data for the North Okanagan Regional District (RDNO) over various time frames using the Pacific Climate Impacts Consortium (PCIC) Plan2Adapt tool. The PCIC projections are based on median values from 12 different Global Climate Models (GCMs) and the Representative Concentration Pathway (RCP) 8.5 greenhouse gas emission scenario. The 2080's time horizon has the largest projected increase in temperature and precipitation compared to historic values (**Table 4-1**). The temperature is projected to increase by 5.0 °C by the 2080's period. Furthermore, PCIC projects a 14% decrease in summer rainfall, a 9.5% increase in winter rainfall, and 45% decrease in annual snowfall by the 2080's period.

Future climate change could lead to changes in the hydrologic regime, including shifts in the timing and duration of runoff. Decreased snowfall and summer precipitation may lead to reduced freshet flows and less extreme floods.

Table 4-1
PCIC Plan2Adapt North Okanagan Regional District Results

PCIC Plan2Adapt North Okanagan Regional District: Projected Change from 1961-1990 Baseline							
		2020's (2010 - 2039)		2050's (2040 - 2069)		2080's (2070 - 2099)	
Climate Variable	Season	Ensemble Median	Range (10th to 90th percentile)	Ensemble Median	Range (10th to 90th percentile)	Ensemble Median	Range (10th to 90th percentile)
Temperature (°C)	Annual	+1.7°C	+1.3°C to +2.0°C	+3.2°C	+2.1°C to +4.2 °C	+5.0°C	+3.7°C to +6.7°C
Precipitation (%)	Annual	-1.2%	-3.0% to +3.0%	+0.13%	-2.1% to +7.2%	+5.1%	-3.2% to +14%
	Summer	-5.3%	-19% to +1.1%	-7.7%	-33% to +0.81%	-14%	-44% to +3.7%
	Winter	-0.6%	-5.6% to +7.5%	+3.5%	-1.1% to +9.3%	+9.5%	-0.081% to +20%
Precipitation as Snow (%)	Annual	-19%	-24% to -13%	-29%	-35% to - 25%	-45%	-52% to -40%
	Winter	-12%	-19% to -5.5%	-19%	-26% to - 16%	-36%	-40% to -27%
	Spring	-36%	-41% to -25%	-49%	-62% to - 38%	-72%	-83% to -58%

4.2 Pacific Climate Impacts Consortium: Station Hydrologic Model Output

Associated used PCIC Hydrologic Model Output to estimate climate change induced changes in the peak flow at the bridge. The PCIC Station Hydrologic Model Output provides simulated flow data at 190 locations in the Pacific Northwest region of North America. Simulated flow is derived based on a Variable Infiltration Capacity (VIC-GL) model coupled with a glacier model and routing model. The Station Hydrologic Model output includes simulated historical flow data (1945 to 2012) based on the PCIC's gridded meteorological data and simulated flow data for 12 scenarios (six GCMs and two RCPs) for the period between 1945 and 2099.

Creighton Creek is an ungauged watercourse. *Mission Creek Near East Kelowna* Water Survey of Canada (WSC) hydrometric station (No. 08NM116) was selected as a surrogate station to assess the possible impacts of climate change on flood flows at the bridge. This hydrometric station is relatively close to Creighton Creek and was also included in the regional regression analysis discussed in **Section 5.3**.

Associated analyzed the flow data using an approach based on MoTI's Canadian Water Resources Associate (CWRA) workshop presentation (Sullivan 2019). The RCP 4.5 and RCP 8.5 emission scenarios were analyzed using 6 different GCMs. The time series were generated based on the average of the six GCM value for each time step for both the RCP 4.5 and RCP 8.5 concentration pathways. Next, the peak annual flow projected for each year from 2030 to 2099 was determined and grouped the data into five periods (2030-2059, 2040-2069, 2050-2079, 2060-2089, 2070-2099). Associated completed an extreme value analysis on the data for each 30-year period and compared the results against the baseline data period (1945-2012). Statistical analysis was completed using HEC-SSP (US ACE 2019) and the Gumbel statistical distribution.

Frequency analyses was completed on the timeseries derived from the mean GCM value for the RCP 8.5 and RCP 4.5 concentration pathways. The peak flow rates determined from the frequency analyses were compared against the baseline historical flow rates. The result indicates that peak flows may decrease in the future. **Figure 4-1**, **Figure 5-2**, and **Table 4-2** show the comparison of projected flow rates against the baseline conditions. The figures show the calculated 2-, 5-, 10-, 20-, 50-, 100, and 200- return period flow rates determined based on the frequency analysis of simulated flows for each 30-year period and the historical data. **Table 4-2** provides the comparison in tabular format.

Peak flow rates in Creighton Creek occur during the spring freshet. Annual snowfall and summer precipitation are forecasted to decrease significantly over the 2050 and 2080 periods, which could lead to reduced snowpack melting and lower freshet flows. A projected climate change driven decrease in peak flows is not surprising based on the projected changes to the regional climate parameters summarized in **Table 4-1.**

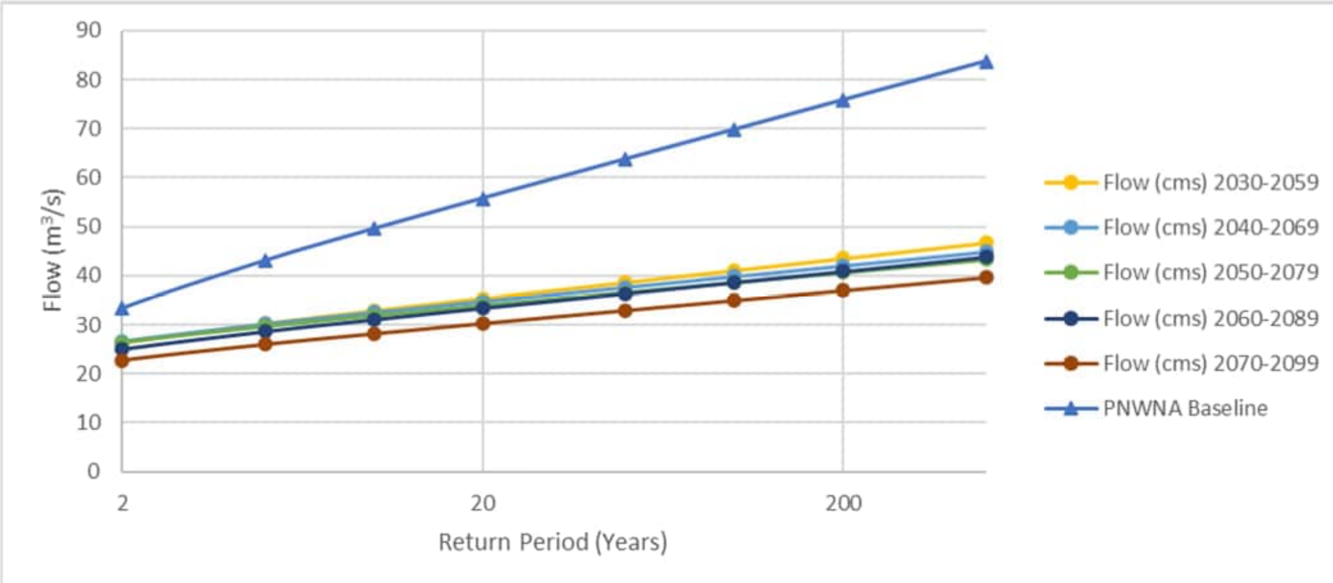


Figure 4-1
Comparison of Projected Flow Rate Against Baseline Data Period (1945-2012) Mean GCM Derived Time Series for the RCP 8.5 Concentration Pathway

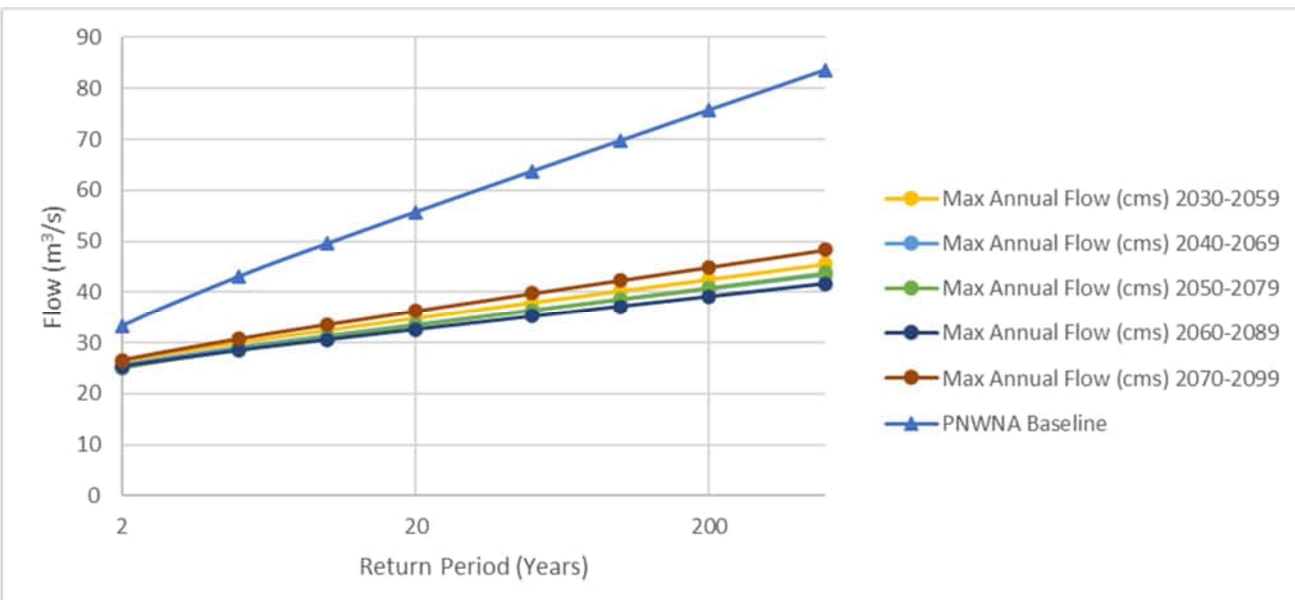


Figure 4-2
Comparison of Projected Flow Rate Against Baseline Data Period (1945-2012) Mean GCM Derived Time Series for the RCP 4.5 Concentration Pathway

Table 4-2
Percent Increase in the Projected 200-Year Peak Instantaneous Flow Rate (based on the mean GCM) Relative to Historical Flow Rate (Based on the PNWA Baseline)

RCP Emission Scenario	Time Series Derivation	2030-2059	2040-2069	2050-2079	2060-2089	2070-2099
RCP 4.5	Mean of GCMs	-44%	-46%	-46%	-48%	-41%
RCP 8.5	Mean of GCMs	-43%	-45%	-46%	-46%	-51%

4.3 Design Flow Climate Change Allowance

The climate change analysis was completed by reviewing the Plan2Adapt tool and analyzing mean flow values for six GCM scenarios. The flow analysis indicates that peak flows in Creighton Creek could decrease in the future. There will be future climate change variability and there is uncertainty in the PCIC Station Hydrologic Model Output data. Therefore, Associated applied a 10% increase to estimate the design flow for the bridge and this increase is consistent with EGBC (2018).

The MoTI *Design Criteria Sheet for Climate Change Resilience* is provided in **Appendix B**.

5 HYDROLOGICAL DESIGN FLOW ANALYSIS

Section 5 of this report summarizes the hydrological analysis completed to determine the design flow for the bridge (200-year peak instantaneous flow). Associated also determined 200-year maximum daily flow and 100-year peak instantaneous flow at the bridge. The 200-year maximum daily flow was estimated to determine the minimum design flow required to satisfy the requirements of the *Water Sustainability Regulation* (Province of BC 2020). The 100-year peak instantaneous flow is the design criterion for low volume roads which have lower ADDT than Daly Bridge. The 100-year flow rate was also determined and modelled to evaluate the difference in the bridge soffit elevation and erosion protection required to achieve the 200-year and 100-year peak instantaneous flow design criteria.

5.1 Hydrometric Data

Associated is not aware of any hydrometric records on Creighton Creek. In the absence of site-specific data, Associated completed a regional hydrological analysis to estimate flows at the bridge. WSC hydrometric stations within a 50 km radius of the bridge were reviewed. A long list of available WSC hydrometric stations was established and this was narrowed down to nine stations for the regional regression analysis (**Figure 5-1**). Stations were selected based on watershed area, length and age of record, quality of data, availability of peak flow data, and unregulated / regulated status. The nine hydrometric stations included in the regional analysis are summarized in **Figure 5-1**.

Table 5-1
WSC Hydrometrics Stations Used in Hydrological Analysis

WSC No.	Station Name	Watershed Area (km^2)	Period of Record	Number of Years with Flow Data
08NM146	Clark Creek Near Winfield	15.3	1968 - 2021	19
08NM142	Coldstream Creek Above Municipal Intake	60.6	1967 - 2021	46
08LC040	Vance Creek Below Deafies Creek	70.9	1970 – 2021	48
08NM172	Pearson Creek Near The Mouth	73.6	1970 – 1987	17
08NM174	Whiteman Creek Above Bouleau Creek	114	1970 – 2021	44
08LC006	Duteau Creek Near Lavington	172	1919 - 1998	25
08LC042	Bessette Creek Above Lumby Lagoon Outfall	632	1973 – 2021	46
08LC039	Bessette Creek Above Beaverjack Creek	769	1970 - 2021	44
08NM116[1]	Mission Creek Near East Kelowna	795	1949 - 2021	67

[1]The *Mission Creek Near East Kelowna* hydrometric station (Station 08NM116) is located further than 50 km from Daly Bridge. However, much of the watershed area is within a 50 km radius of the bridge.

5.2 Statistical Frequency Analysis

Associated completed an extreme value analysis on the peak instantaneous flow and maximum daily flow data from each WSC hydrometric station listed in **Figure 5-1**. Prior to completing the statistical analysis, the average ratio of the peak instantaneous flow (I) to the maximum daily flow (D) for each station was calculated. Then the maximum daily flow was multiplied by the average I/D ratio to estimate the instantaneous flow for years missing peak flow data. The estimated peak flow data was included in the extreme value analysis.

Statistical frequency analysis was completed using HEC-SSP (US ACE 2019). The five statistical distributions considered in the analysis were: Log Normal, Log Pearson III, Generalized Extreme Value, Gamma, and Gumbel. The Cunnane plotting position was used in this analysis (Pilon and Harvey 1993). Statistical results were based on the calculated average from the five statistical distributions. The Log Normal distribution did not fit the Station 08LC006 flow data well and was not consistent with the other four statistical distributions. Therefore, the flow estimates for Station 08LC006 were estimated based on the average of the other four statistical distributions.

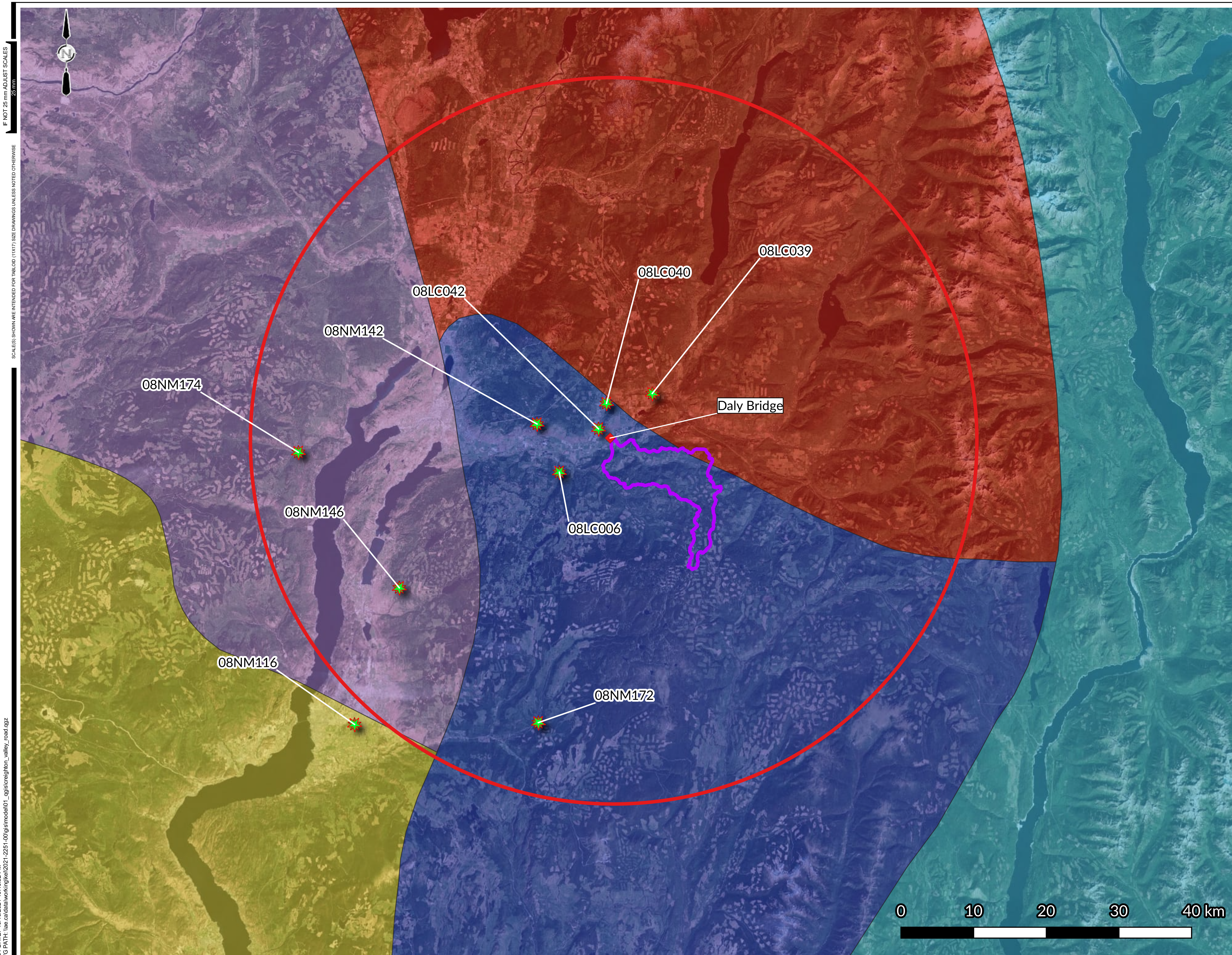
5.3 Regional Regression Analysis for Design Flow

The results of the frequency analyses for each WSC hydrometric station are shown in **Figure 5-2**, **Figure 5-3**, and **Figure 5-4**. The regression curve and 95% confidence limits are shown on each graph. The 100-year peak instantaneous, the 200-year maximum daily, and the 200-year peak instantaneous coefficients of determination (R^2) for the regional regression curves are 0.82, 0.88, and 0.81 respectively, indicating that the flow rates of the selected watersheds are adequately represented by the relation between watershed area and flow.

Based on the regional regression curves and watershed area at the site (102.6 km^2), the best fit results are:

- 100-year peak instantaneous flow estimate without climate change is 18.3 m^3/s.
- 200-year peak instantaneous flow estimate without climate change is 20.4 m^3/s.
- 200-year max daily flow estimate without climate change is 15.9 m^3/s.

The *Water Sustainability Regulation* (Province of BC 2020) requires all bridges be designed to convey the 200-year return period maximum daily flow. Both the 100-year and 200-year peak instantaneous flow rate are larger than the 200-year maximum daily and would exceed the requirement of the *Water Sustainability Regulation*. The bridge should be designed based on the 200-year peak instantaneous flow rate to comply with the MoTI hydrological design criterion for Collector Roads.



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LEGEND

- Daly Bridge
- Daly Bridge Catchment Area
- Hydrometric Station

Hydrologic Zone

- 14
- 15
- 22
- 23
- 24
- 50 km Radius From Daly Bridge

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

FIGURE 5-1

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

DALY BRIDGE REGIONAL ANALYSIS HYDROMETRIC STATIONS

AE PROJECT No.	2021-2251-00
SCALE	1 : 500,000
APPROVED	G. CAHILL
DATE	2023MAR
REV	A
DESCRIPTION	ISSUED FOR REPORT

IF NOT 25 mm ADJUST SCALES

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

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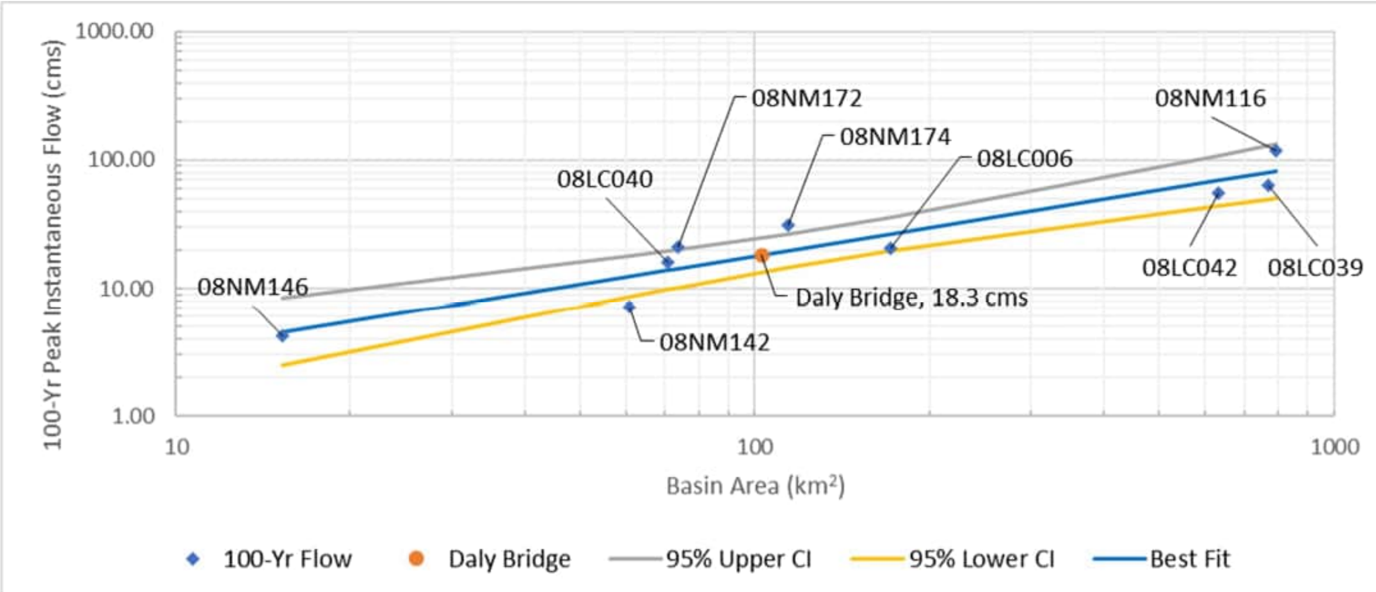


Figure 5-2
Regional Regression Curve with 95% Confidence Limits for 100-Year Peak Instantaneous Flow (Without Climate Change)

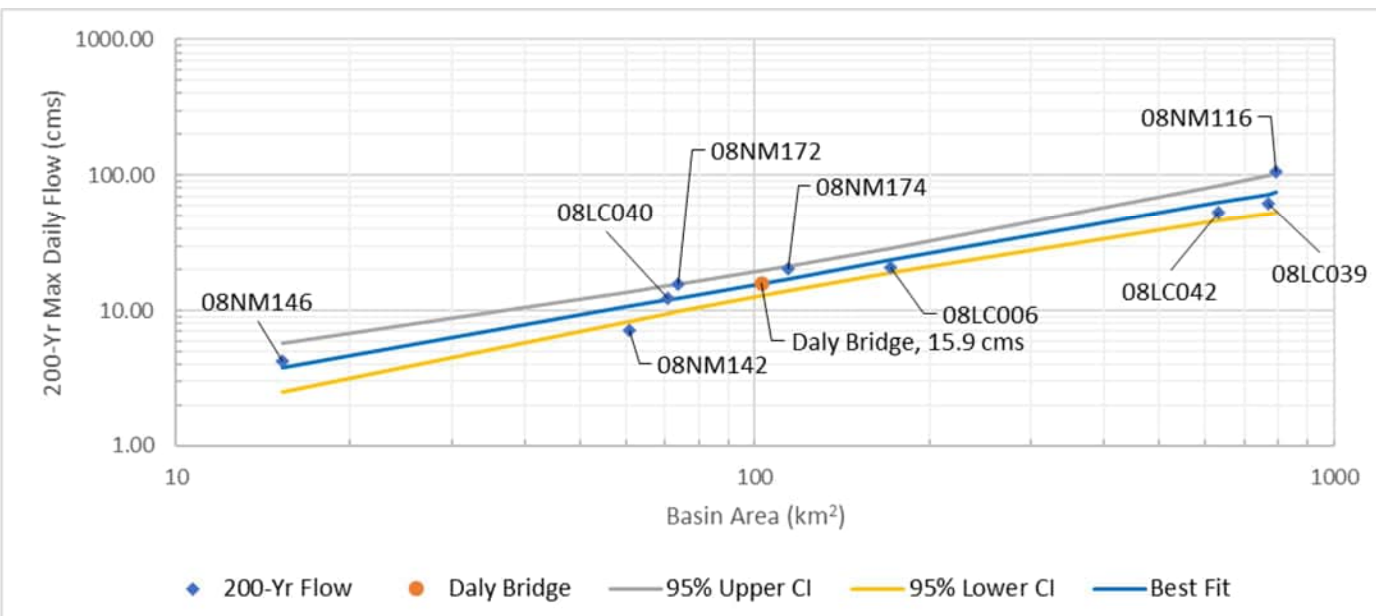


Figure 5-3
Regional Regression Curve with 95% Confidence Limits for 200-Year Max Daily Flow (Without Climate Change)

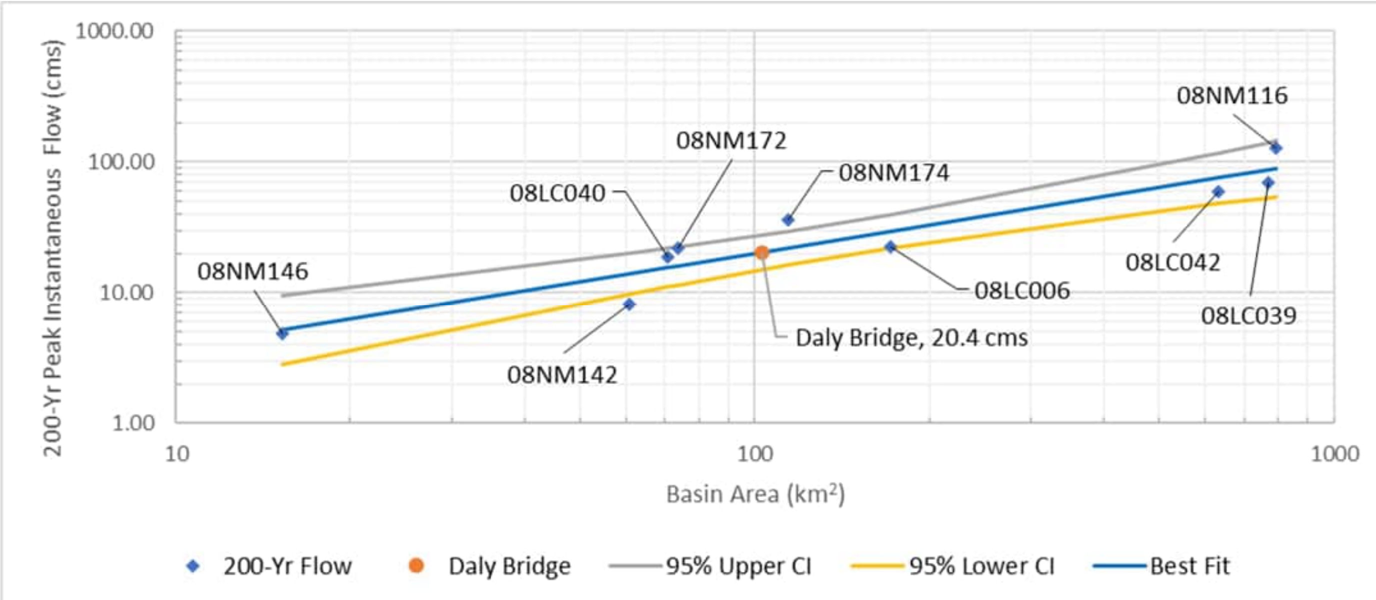


Figure 5-4

Regional Regression Curve with 95% Confidence Limits for 200-Year Peak Instantaneous Flow (Without Climate Change)

5.4 Synthetic Hydrograph

To support unsteady flow modelling, Associated evaluated *Whiteman Creek above Bouleau Creek* (Station Number 08NM174) as a surrogate watershed. Whiteman Creek has a similar watershed area and elevation range compared to Creighton Creek. Recorded flows from 2008, 2017, and 2018 were large freshet events in Whiteman Creek and were chosen to represent the general duration and shape of design flood events in Creighton Creek. The recorded hydrographs were scaled so that the peak flow of the synthetic hydrograph was equivalent to peak flow at the bridge. The resulting synthetic hydrographs were applied as the upstream boundary condition in the hydraulic model. The design hydrographs used in the hydraulic model are shown in **Figure 5-5**.

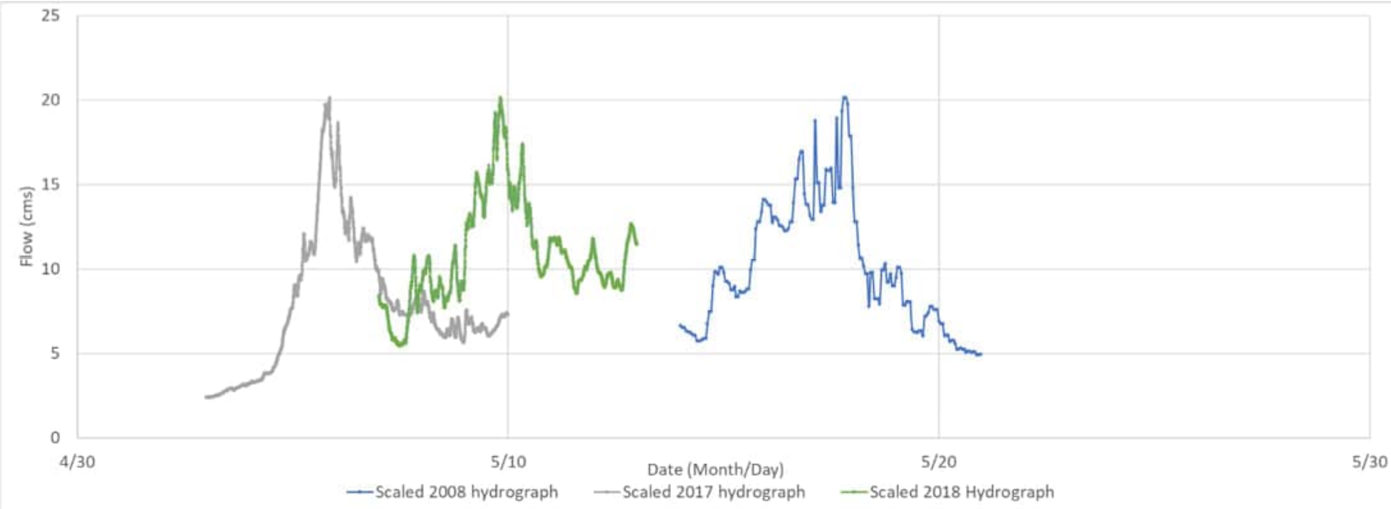


Figure 5-5
100-year Return Period Design Hydrographs

5.5 Construction Period Flow Rates

Creighton Creek provides habitat for Coho Salmon and Rainbow Trout (FLNRO 2018). The annual least risk instream work window for Creighton Creek is August 7 to October 21. A frequency analysis on the maximum daily flow for the period from August to October was completed for each WSC hydrometric station listed in **Table 5-2**. The statistical frequency analysis was completed using HEC-SSP software based on the same five statistical distributions considered in the design flow regional analysis. The 10-year maximum daily flow for the August to October construction period is 1.2 m^3/s.

5.6 Summary of Flow Estimates and Design Flow

The flow estimates are summarized in **Table 5-2** which includes the recommended design flow of 22.5 m^3/s.

Table 5-2
Design Flows for Daly Bridge

Scenario	Flow (m^3/s)
100-yr Peak Instantaneous Flow (With Climate Change)	20.1
200-yr Maximum Daily Flow (With Climate Change)	17.5
DESIGN FLOW **200-yr Peak Instantaneous Flow (With Climate Change)**	**22.5**
Construction Period Design Flow (Without Climate Change)	1.2

6 HYDRAULIC ANALYSIS

6.1 Software

The bridge hydraulics were modelled using a 1D/2D GeoHECRAS model. GeoHECRAS is a GIS compatible version of the US Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS). HEC-RAS Version 5.0.7 was used for this analysis.

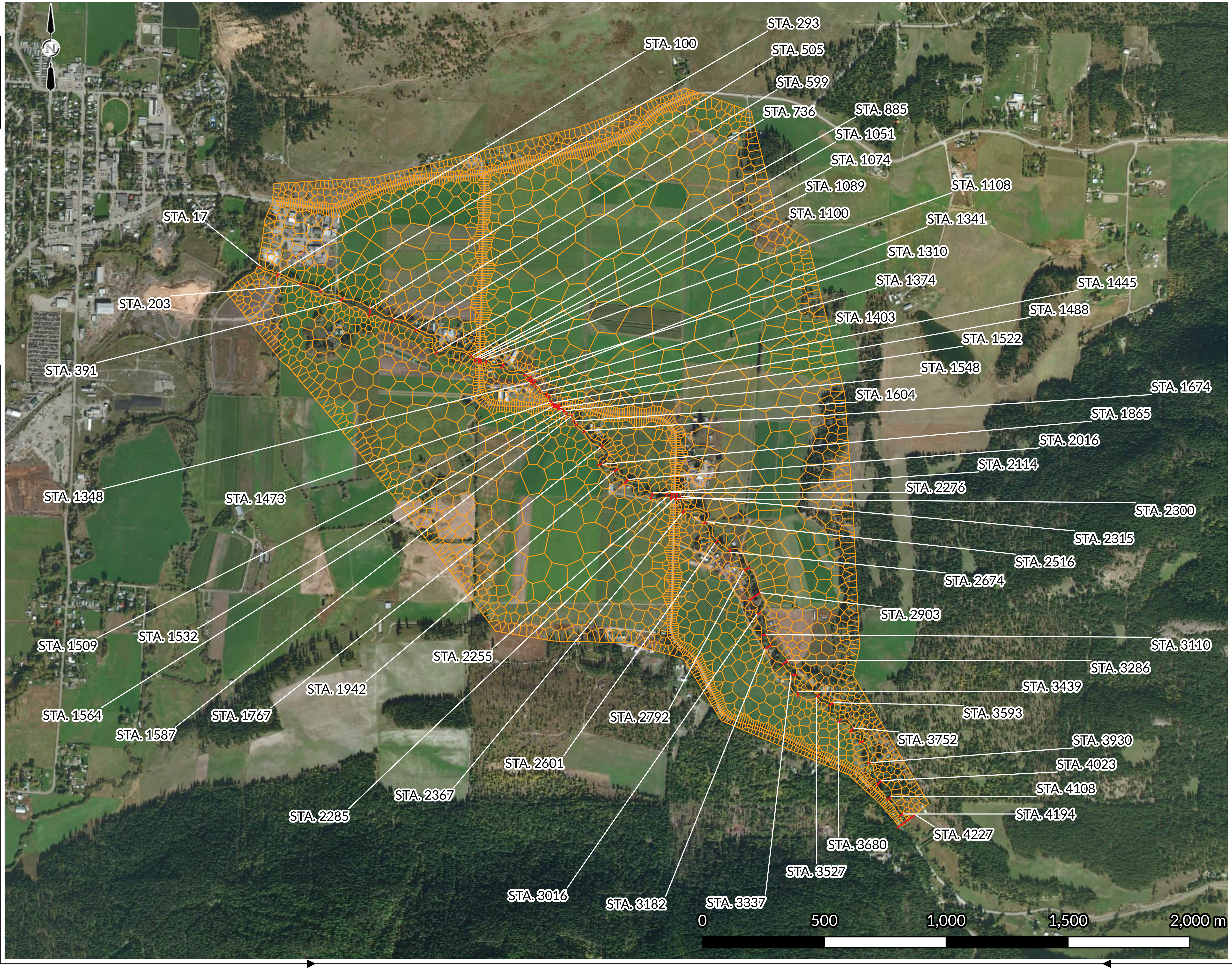
6.2 Geometry Inputs and Model Approach

LiDAR and topographic survey surfaces were provided by MoTI. A combined surface was created and used as the base geometry input for the model (**Figure 6-1**). Topographic survey data was used to represent the channel bed topography extending approximately 150 m upstream and downstream of the bridge. The LiDAR data was used to represent the floodplain and the remainder of the channel beyond the survey extents.

Manning's n values were selected based on site observations and available literature. The creek and adjacent overbank Manning's n values were selected as 0.045 and 0.1. A roughness value of 0.045 was selected to represent a clean, winding, channel with some pools and shoals, and some stones. A Manning's 'n' value of 0.1 was selected to represent the medium to dense brush situated in the riparian corridor along the stream. The remainder of the floodplain was represented by a 2D mesh with a Manning 'n' of 0.7 to account for a mixture of cultivated fields and developed areas.

Contraction and expansion coefficients were modelled as 0.1 and 0.3 respectively, at all cross sections except for the cross sections upstream and downstream of the bridges. These contraction and expansion coefficients were modelled as 0.3 and 0.5 respectively to account for changes at the bridge opening during the design flow event.

The upstream and downstream boundary conditions were selected as normal depth which is the slope of the energy grade line at the upstream and downstream extents. The model analysis was performed using unsteady flow conditions and a subcritical flow regime. The unsteady flow hydrograph was included at the upstream boundary condition.



IF NOT 25 mm ADJUST SCALES

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

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LEGEND

2D Flow Area Cell Face
Cross Section

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

FIGURE 6-1

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

GeoHECRAS Hydraulic Model layout

AE PROJECT No.	2021-2251-00
SCALE	1 : 15,000
APPROVED	G. CAHILL
DATE	2023MAR
REV	A
DESCRIPTION	ISSUED FOR REPORT

6.3 Hydraulic Model Results

Creighton Creek is between 4 m and 5 m wide in the vicinity of the bridge. Associated considered 5 m, 6 m, and 7 m bridge opening options to avoid constricting the channel. These three bridge opening options were analyzed during the 200-year peak instantaneous flow event. This analysis demonstrated that increasing the bridge opening width beyond 5 m does not significantly lower the water surface elevation at the bridge. Based on this analysis a 5 m opening width was selected for the bridge. Water level and velocity were also evaluated through the proposed 5 m bridge opening during the 100-year peak instantaneous design flow rate for comparison against the design flow. The results of the HEC-RAS analysis are summarized in **Table 6-2**.

Table 6-1
Hydraulic Conditions at Bridge

Bridge Opening Scenario	Flow Hydrograph Year	Peak Instantaneous Flow Return Period	Design Flow (m^3/s)	Average Channel Velocity (m/s)	Water Surface Elevation (m)	Minimum Bridge Soffit Elevation (m)	Minimum Freeboard (m)[1]
5 m Width	**2017**	**200-year**	**22.5**	**1.40**	**503.75**	**504.75**	**1.0**
	2018	**200-year**	**22.5**	**1.40**	**503.75**	**504.75**	**1.0**
	2008	**200-year**	**22.5**	**1.41**	**503.75**	**504.75**	**1.0**
6 m Width	2017	200-year	22.5	1.33	503.74	**504.74**	1.0
	2018	200-year	22.5	1.33	503.74	505.74	1.0
	2008	200-year	22.5	1.33	503.74	504.74	1.0
7m Width	2017	200-year	22.5	1.26	503.73	504.73	1.0
	2018	200-year	22.5	1.26	503.73	504.73	1.0
	2008	200-year	22.5	1.26	503.73	504.73	1.0
5 m Width	2017	100-year	20.5	1.38	503.73	504.23	0.5
	2018	100-year	20.5	1.38	503.73	504.23	0.5
	2008	100-year	20.5	1.39	503.73	504.23	0.5

[1]A 1.0 m freeboard between the 200-year peak instantaneous water level and the bridge soffit was selected as part of the bridge design exception. This freeboard is 0.5 m lower than is required in the BC Supplement to S6-14 Clause 1.9.7.1.

The water level (503.75 m) at the upstream face of the bridge and the average channel velocity (1.40 m/s) in the vicinity of the bridge during the design flow was determined. **Figure 6-2** and **Figure 6-3** illustrate the HEC-RAS model results for the Daly Bridge. **Figure 6-2** shows the longitudinal water surface profile and **Figure 6-3** shows the cross sections results at the upstream side of Daly Bridge. It is noted that there is overland flooding during the design flow simulation. The Creighton Creek floodplain has water flowing overland, so flow is divided and only a portion of the flow is conveyed through the bridge opening under design conditions.

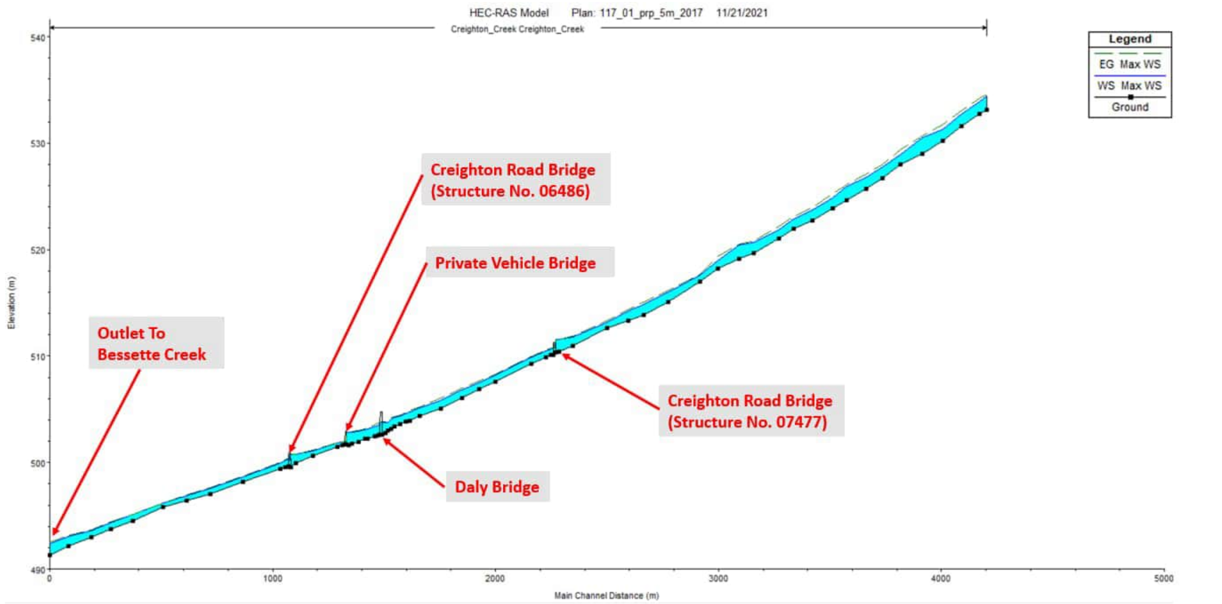

Figure 6-2

200-Year Return Period Channel Profile (For Proposed Bridge Opening with 5 m Bottom Width)

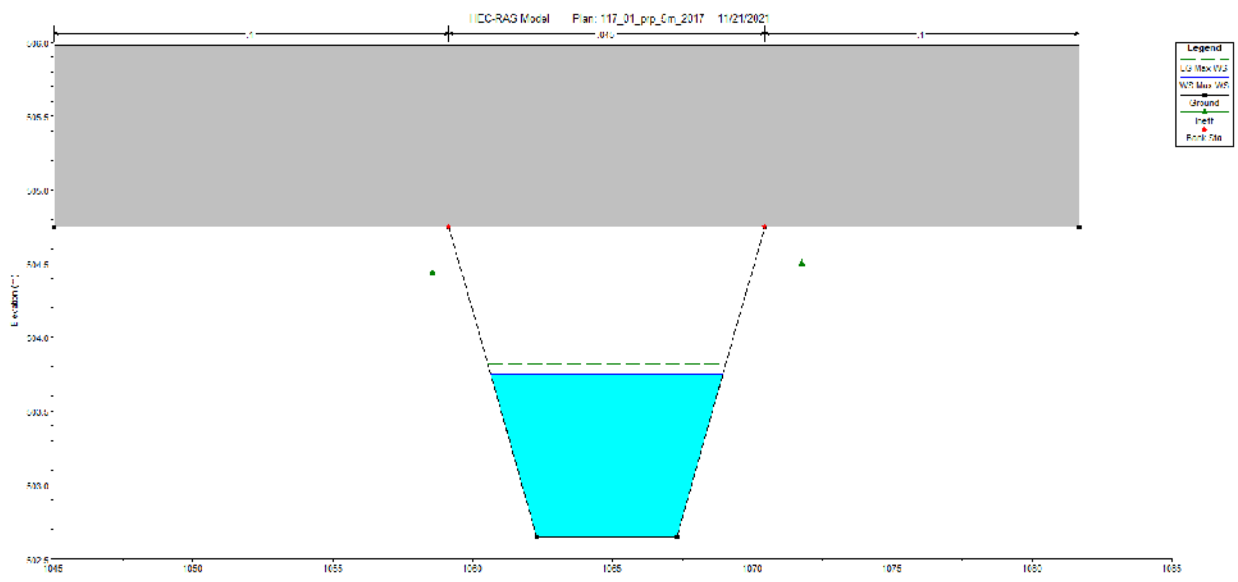

Figure 6-3

Upstream Bridge Cross Section For Design Flow (Proposed Bridge Opening with 5 m Bottom Width)

6.4 Scour Depth

Contraction scour, abutment scour, and natural scour were evaluated at the bridge. Contraction and abutment scour depths were assessed using the bridge scour tool in HEC-RAS software, which applies FHWA HEC-18 methods. Scour was analyzed based on the depth and velocity at cross sections located at the approach and immediately upstream of the bridge. The results of this analysis indicate that no contraction or abutment scour is projected at the bridge. These results are not surprising as the bridge base width was selected to avoid any contraction of the channel and the design velocity is reasonably low.

Natural scour was calculated using Neill (1973), Lacey (1930), and Blench (1969) (USBR 1984) formulas. No bed sampling or sieve analysis was completed on the bridge bed material. Associated completed the scour analysis based on an estimated D_{50} of 10 mm, corresponding to the particle size range for a mixture of sand and gravel. Associated estimated the grain size based on field observations. An average of the results of the three approaches was calculated and a safety factor of 1.2 was applied. An estimated natural scour depth is 0.8 m below the existing bed at the site, which is recommended for design.

6.5 Scour and Erosion Protection

6.5.1 Sizing

The Maynord method (USACE 1994) was used to size riprap protection based on site conditions and hydraulic results. This method determines the necessary riprap protection based on various parameters including channel characteristics, channel type, and radius of curvature. The channel characteristics affect the riprap size calculations, whereas the channel type and radius affect the design velocity. **Table 6-2** summarizes the Maynord equation results. Based on a safety factor of 1.1, 100 kg riprap is required to protect the bridge abutments and approach. The riprap bank protection should be installed as per recommendations from the MoTI (2013). In addition, the riprap should be keyed in 0.8 m below the channel bed to provide scour protection.

Table 6-2
Riprap Sizing at Bridge Abutment

Location	Design Velocity (m/s)	Riprap Slope (H:1V)	Recommended Design Riprap Class (kg)	Nominal Thickness (mm)
Daly Bridge	2.97	1.5	100	700 (min.)

6.5.2 Arrangement

Through the environmental and regulatory review process of the project there were hydrotechnical design revisions made for the bridge. Alternative riprap arrangements were made to mitigate potential adverse impacts to Creighton Creek. The hydrotechnical design includes two types of riprap scour and erosion protection:

- Bank armouring, and
- Trenching

Bank armouring is the traditional arrangement of riprap placed on the constructed channel bank. This arrangement follows standard installations procedures from the MoTI.

Trenching is the alternative riprap arrangement, which was included to minimize instream works. This arrangement includes excavating a linear trench that is setback from the channel and filling the trench with riprap. The riprap is sacrificial and would become exposed in the event of future bank erosion, thereby providing scour and erosion protection for the bridge.

6.6 Large Wood

As described in the geomorphological assessment, large wood was observed in the channel and along the banks of Creighton Creek. Through the environmental and regulatory review process of the project there were hydrotechnical design revisions made for the bridge. One of the design revisions was the inclusion of large wood features in the design. Large wood can be used as an alternative to (or supplement) traditional riprap scour and erosion protection, and provides habitat features in the channel. Large wood is proposed in the hydrotechnical design in locations shown on the drawings. The large wood pieces must be ballasted with boulders for stability in the channel.

6.7 Live Staking

Another design revision was the replacement of riprap with live staking on the downstream right bank of the bridge. This was the only location suitable for live staking installation following the other design revisions for the bridge. The upper portion of the bank will have live staking as an alternative to riprap. The riprap elevation will stop at the 50-year water level and live stakes will be placed above this level. This design approach was included following discussion with the MoTI. Live staking is a form of bio-engineering and can be applied in low-velocity locations. The vegetation supports bank protection, soil stability, channel shade, and aesthetics.

7 HYDROTECHNICAL DESIGN RECOMMENDATIONS

The scope of the hydrotechnical assessment was to complete design for the bridge. The recommended hydrotechnical design values are summarized in **Table 7-1**.

Table 7-1
Summary of Hydrotechnical Design Recommendations

Hydrotechnical Design Parameters	Design Recommendations
Hydrological Design Criterion	200-Year Instantaneous
Flow without Climate Change Adaptation	20.4 m^3/s
Recommended Flow Increase for Climate Change Adaptation	+ 10%
Design Flow	22.5 m^3/s
Bridge Opening Minimum Bottom Width	5 m
Bank Side Slopes	1.5H (min.) : 1V
Design Flow Water Elevation	503.75 m
Design Flow Water Depth	1.13 m
Minimum Freeboard	1.0 m
Minimum Soffit (Low Chord) Elevation	504.75 m
Average Channel Velocity	1.4 m/s
Design Velocity at Daly Bridge	2.97 m/s
Estimated Scour Depth, and Minimum Riprap Toe Key Depth	0.8 m
Recommended Riprap Class for Erosion and Scour Mitigation at Daly Bridge	100 kg
Recommended Bed Elevation to Trigger Channel Dredging	503.62 m
Large Wood Features: **Tree Trunk (with Root Wad Still Intact) Diameter** **Tree Trunk (with Root Wad Still Intact) Length** **Ballast Boulder Diameter**	 0.5 m (min.) 2.5 m (min.) 0.75 m (min.)

CLOSURE

This report was prepared for the Ministry of Transportation and Infrastructure to summarize the hydrotechnical analysis completed to support the 100% Daly Bridge replacement design.

The services provided by Associated Engineering (B.C.) Ltd. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No other warranty expressed or implied is made.

Respectfully submitted,

Associated Engineering (B.C.) Ltd.
Engineers & Geoscientists BC Permit Number 1000163

Prepared By:	Reviewed By:
	2023-03-24
Sean Haley, EIT Hydrotechnical Engineer	Geoffrey Cahill, P.Eng. Senior Hydrotechnical Engineer

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APPENDIX A - SITE PHOTOS

Photo 1 Creighton Road Bridge (Structure No. 06486)

Photo 2 Pedestrian Bridge No. 1 (Upstream of Creighton Road Bridge (Structure No. 06486)

Photo 3 Private Vehicle Bridge (Approximately 150 m Downstream of Daly Bridge)

Photo 4 Daly Bridge (Structure No. 0689)

Photo 5 Pedestrian Bridge No. 2 (Downstream of Creighton Road Bridge (Structure No. 07477)

Photo 6 Creighton Road Bridge (Structure No. 07477)

APPENDIX B - DESIGN CRITERIA SHEET FOR CLIMATE CHANGE RESILIENCE

Design Criteria Sheet for Climate Change Resilience

Highway Infrastructure Engineering Design and Climate Change Adaptation
BC Ministry of Transportation and Infrastructure
(Separate Criteria Sheet per Discipline)
(Submit all sheets to the Chief Engineers Office at: BCMoTI-ChiefEngineersOffice@gov.bc.ca)

Project:	*Daly Bridge 06489 Replacement*
Type of work:	*Bridge Structures*
Location:	*Creighton Valley Road, Lumby, BC*
Discipline:	*Hydrotechnical*

Design Component	Design Life or Return Period	Design Criteria + (Units)	Design Value Without Climate Change	Change in Design Value from Future Climate	Design Value Including Climate Change	Adaptation Cost Estimate ($)	Comments / Notes / Deviations / Variances
Bridge	200 yr RP	Flow Rate (m^3/s)	20.4	+10%	22.5		- See notes below

Explanatory Notes / Discussion:

PCIC Plan2Adapt Review

Associated Engineering reviewed climate change projection information for the North Okanagan Regional District over various time frames using the Pacific Climate Impacts Consortium (PCIC) Plan2Adapt tool. The PCIC projections are based on median values from 12 different Global Climate Models (GCMs) and the Representative Concentration Pathway (RCP) 8.5 greenhouse gas emission scenario. The 2080's time horizon (2070-2099) has the largest projected increase in temperature and precipitation compared to historic values. The temperature is projected to increase by 5.0 °C by the 2080's period. Furthermore, PCIC projects a 14% decrease in summer rainfall, a 9.5% increase in winter rainfall, and 45% decrease in annual snowfall by the 2080's period. Future climate change could lead to changes in the hydrologic regime, including shifts in the timing and duration of runoff. Decreased snowfall and summer precipitation may lead to reduced freshet flows and less extreme floods in Creighton Creek.

PCIC Hydrologic Model Output

Associated Engineering used PCIC Hydrologic Model Output to estimate climate change induced changes in the peak flow at the bridge. The PCIC Station Hydrologic Model Output provides simulated flow data at 190 locations in the Pacific Northwest region of North America. Simulated flow is derived based on a Variable Infiltration Capacity (VIC-GL) model coupled with a glacier model and routing model. The Station Hydrologic Model output includes simulated historical flow data (1945 to 2012) based on the PCIC's gridded meteorological data and simulated flow data for 12 scenarios (six GCMs and two RCPs) for the period between 1945 and 2099.

Creighton Creek is an ungauged watercourse. Mission Creek Near East Kelowna Water Survey of Canada (WSC) hydrometric station (No. 08NM116) was selected as a surrogate station to assess the possible impacts of climate change on flood flows at the bridge. This hydrometric station is relatively close to Creighton Creek and was also included in the regional regression analysis for the bridge. The RCP 4.5 and RCP 8.5 emission scenarios were analyzed using 6 different GCMs. The time series were generated based on the average of the six GCM value for each time step for both the RCP 4.5 and RCP 8.5 concentration pathways. The peak annual flow projected for each year from 2030 to 2099 was determined and grouped the data into five periods (2030-2059, 2040-2069, 2050-2079, 2060-2089, 2070-2099). Associated Engineering completed an extreme value analysis on the data for each 30-year period and compared the results against the baseline data period (1945-2012).

The peak flow rates determined from the frequency analyses were compared against the baseline historical flow rates. The result indicates that peak flows may decrease in the future for all scenarios. Peak flow rates in Creighton Creek occur during the spring freshet. Annual snowfall and summer precipitation are forecasted to decrease significantly over the 2050 and 2080 periods, which could lead to reduced snowpack melting and lower freshet flows. A projected climate change driven decrease in peak flows is not surprising based on the projected changes to the regional climate parameters.

Climate Change Summary

The climate change analysis was completed by reviewing the Plan2Adapt tool and analyzing mean flow values for six GCM scenarios. The flow analysis indicates that peak flows in Creighton Creek could decrease in the future. There will be future climate change variability and there is uncertainty in the PCIC Station Hydrologic Model Output data. Therefore, Associated Engineering applied a 10% increase to estimate the design flow for the bridge and this increase is consistent with EGBC.

Refer to the Associated Engineering Daly Bridge 06489 Replacement 100% Hydrotechnical Design report (March 2023).

Recommended by: Engineer of Record: Geoffrey Cahill, P.Eng.
(Print Name / Provide Seal & Signature)

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — G. S. CAHILL # 38248

2023-03-24

Date: March 23, 2023

Engineering Firm: Associated Engineering (B.C.) Ltd.

Accepted by BCMoTI Consultant Liaison: ____
(For External Design)

Deviations and Variances Approved by the Chief Engineer: ______________________________
Program Contact: Chief Engineer BCMoTI