

Impacts to Highway 8 British Columbia due to the November 2021 Atmospheric River Event

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ABSTRACT

The section of Highway 8 between Spences Bridge and Lower Nicola British Columbia suffered significant damage during the atmospheric river event of November 2021 with multiple sections of the highway completely washed away and destroyed due to flooding and lateral migration of the Nicola River, along with access to small farming and Indigenous communities along the highway cut off. The damage included a total of 6 km of highway that was completely eroded away, with a further 1 km of highway and 3 highway bridges compromised. Additional damage in the corridor included 4 private or secondary road bridges that were washed away, with a further 4 compromised along with 5 bridges associated with the historic Kettle Valley Railway also lost. The damage through this corridor was significantly amplified in areas due to the vulnerability of glacial drift soils to erosion, the impacts from a wildfire that occurred in the summer of 2021 and the presence of natural and artificial hydraulic constrictions along sections of the Nicola River. The resulting flood damage created multiple geohazards for the response team to contend with including some significant landslide hazards that in one extreme case resulted in an approximately 3 km section of the highway shifted onto the historic Kettle Valley Railway alignment. This paper provides a summary of the impacts that the flood had to the highway, including the influence of hydraulic constrictions and erodible soils, as well as the significant landslide hazards created by the flood and how they were addressed by the flood response team during the emergency access phase (Phase 1).

RÉSUMÉ

La section d'autoroute 8 entre le pont Spences et la région de Lower Nicola, en Colombie-Britannique, a subi des dommages importants à la suite de la rivière atmosphérique en novembre 2021. Plusieurs sections de l'autoroute ont été complètement érodées et détruites résultant de l'inondation ainsi que du mouvement latéral de la rivière Nicola – ce qui a coupé l'accès à certaines communautés agricoles et indigènes locales. Le bilan comptait un total de 6 km d'autoroute, quatre ponts privés et ponts routiers secondaires qui se sont complètement effondrés, ainsi qu'un kilomètre d'autoroute, trois ponts de chaussées et quatre ponts routiers secondaires qui ont été compromis. Les dégâts incluaient aussi l'écroulement de cinq ponts liés au sentier historique Kettle Valley Railway. Les dommages subis étaient davantage amplifiés étant donné la susceptibilité des dépôts glacières quant à l'érosion, l'impact des feux de forêts qui ont survenus pendant l'été 2021 et la présence des étranglements hydrauliques artificielles et naturelles qui longent des sections de la rivière Nicola. L'équipe de réponse a dû faire face à plusieurs dégâts causés par l'inondation, qui par conséquent a créé de nombreux géorisques tels que des glissements de terrain importants. Un cas extrême qui surgit fut une section d'environ 3 km d'autoroute qui s'est écroulée sur avec l'alignement du sentier historique Kettle Valley Railway. Ce papier résume les effets de l'inondation subit par l'autoroute tout en incluant l'influence des étranglements hydrauliques et des sols érosifs ainsi que l'importance du risque de glissements de terrain résultant de l'inondation et comment ce fut adressé par l'équipe de réponse. (Phase 1)

1 INTRODUCTION

Highway 8 is situated in the Southern Interior of British Columbia connecting the communities of Spences Bridge on the TransCanada Highway and Merritt at the junction of Highway 5 (Coquihalla Highway) and Highway 97C (Okanagan Connector), as depicted on Figure 1.

The highway concurrently runs with Highway 97C westward from Merritt to the community of Lower Nicola (Mamit Junction) where it runs for 60.31 km parallel to the Nicola River to the junction with the TransCanada Highway. A review of the British Columbia Ministry of Transportation and Infrastructure traffic count site (<https://www.th.gov.bc.ca/trafficData/>) indicates that the current average annual daily traffic along Highway 8 is approximately 5,000 vehicles.

During the atmospheric river event of November 2021 that impacted southwestern British Columbia, sections of Highway 8 were completely washed away and destroyed due to flooding and lateral migration of the Nicola River, along with access to small agricultural and Indigenous communities along the highway that was cut off.

1.1 Nicola River Catchment

The drainage area of the Nicola River at its confluence with the Thompson River is 7670 km² (“Nichols 1988”), with elevations ranging from 2250 m in the Cascade Mountain to 227 m at its confluence. Gradients along the river range from 0.05% near Merritt to 0.70% along the lower reaches, with an average of 0.47%.

Major tributaries to the Nicola River include the Coldwater River, Spius Creek and Guichon Creek which

have drainage areas of 914, 781 and 1230 km² respectively.

The estimated maximum daily and instantaneous discharge for the Nicola River at its outlet is 380 m³/s and 490 m³/s respectively. Environment and Natural Resources Canada maintains several real-time hydrometric stations within the Nicola River catchment several of which failed during the atmospheric river event.

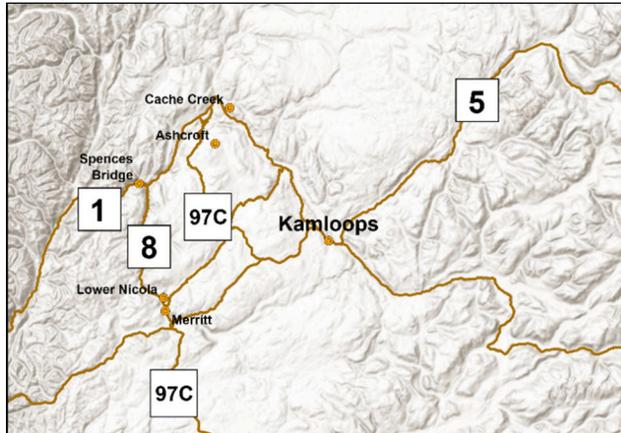


Figure 1. Location of Highway 8.

2 GEOLOGY & GEOMORPHOLOGY

2.1 Bedrock Geology

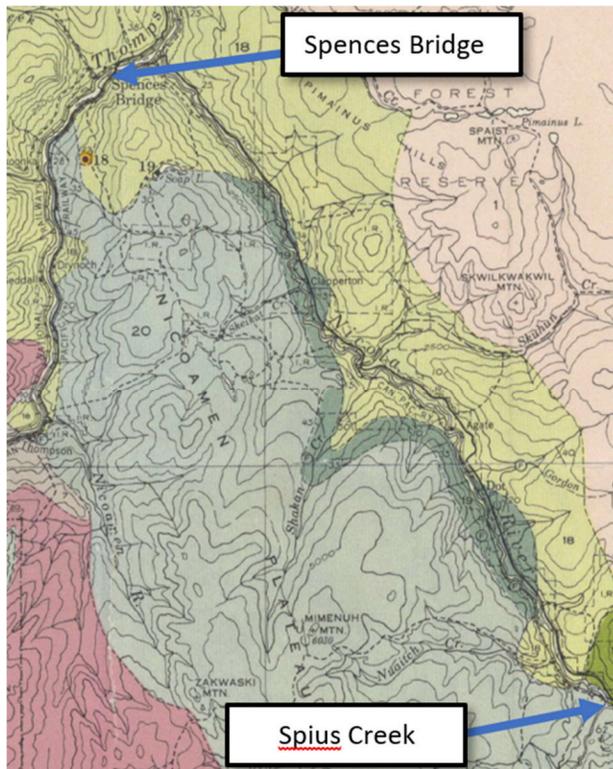


Figure 2. Bedrock Geology of the Nicola River, Spius Creek to Spences Bridge (Duffell et al. 1951).

Bedrock geology along the Highway 8 corridor (Nicola River, downstream of Spius Creek) generally consists of lower cretaceous volcanic rocks of the Spences Bridge Group (andesite, dacite, basalt and rhyolite; tuff, breccia and agglomerate; conglomerate, sandstone, greywacke, and arkose) and Kingsvale Group (Arkose, conglomerate, shale, and greywacke, basalt and andesite; agglomerate, tuff, and breccia) as indicated by the bedrock geology map “Ashcroft, Kamloops, Lillooet and Yale districts, British Columbia” (Duffell et al, 1951). See Figure 2.

2.2 General Geomorphology

The Nicola River valley falls within the Interior Plateau and intersects the Nicoamen Plateau and Pimainus Hills, as described in the “Quaternary Geology – Terrain Inventory Lytton Map-Area, British Columbia” (Ryder 1974).

Ryder describes the Pimainus hills as an “undulating upland with gentle slopes of less than 300m of local relief, but with precipitous dissected margins bordering the Thompson and Nicola valleys”. The Nicoamen Plateau is further described as consisting of rolling upland areas, separated by deep valleys of tributary creeks to the Nicola River. The plateau surfaces and valley slopes are generally covered with drift (till), suggesting minimal postglacial bedrock erosion. Bedrock outcrops are limited to the steepest slopes and higher elevations.

A recent aquifer mapping assignment of the Nicola watershed identified the principal groups of Quaternary sediments as broken into two major periods of non-glacial sedimentation and two separate periods of glaciation for this area (Gorski et al. 2018).

These periods were broken down into the following groups:

- Okanagan Centre Drift-Okanagan Centre Glaciation (Prior to 43,800 B.P.)
- Bessette Sediments-Olympia Interglaciation (Approximately 43,800 to 19,000 B.P.)
- Kamloops Drift - Fraser Glaciation (Approximately 19,000 to 10,500 B.P.)
- Post Glacial Deposits (Approximately 10,500 B.P. to present)

2.3 Surficial Geology

The Quaternary surficial deposits of the Nicola River valley from Spius Creek to Spences Bridge can be generalized into three main groups, based on approximate elevation relative to valley bottom. Figure 3 shows the Quaternary surficial deposits from Highway 8 Damage Sites 1 to 23.

In general, the highest elevation group consists of a combination of till veneer (Mv), ranging from 1 to 2m in average thickness, and till blankets (Mb, Mbm) with thickness greater than 2m. Numerous bedrock outcrops and steep rock/cliffs (R, Rs) are present at higher elevations (Ryter 1974, Plouffe et al. 2018).

There is a mid-elevation transition group consisting of colluvial deposits; colluvial blankets and talus (Cb, Ca),

While most of the high burn intensities occurred in areas with relatively thin till veneer, increased surface runoff could result in increased flows experienced in lower elevation areas comprised of the Nicola Valley Complex (A:Dx), which tend to be more susceptible to erosion and landslide events. A map of the burn intensities for the Lytton Wildfire is depicted on Figure 4.

3 FLOOD EVENT

A strong atmospheric river event occurred over Southwestern British Columbia during November 14th and 15th 2021 that in terms of the associated two-day precipitation has been estimated to be a one in 50-100 year event (Gillett et al. 2022). The effects of the precipitation on streamflow was worsened by snowmelt of early season snowfall and in some catchments increased runoff due to recent wildfire activity.

Review of streamflow hydrometric data for the Nicola River catchment indicated that the majority of runoff was generated in the Coldwater River and Spius Creek watersheds, with peak flows recorded during event exceeding historical estimated Q200 peak instantaneous flows. See Table 1 below for Q200 and maximum flows.

Table 1. Recorded Peak Instantaneous Flows

Hydrometric Station	Estimated Q200 (m ³ /s)	Maximum Flow (m ³ /s)	Recorded
Brookmere 08LG048 ¹	183 ²	302 (2021-11-14 19:10)	
Coldwater River at 08LG010	212 ³	259 (2021-11-15 17:05)	
Spius Creek at 08LG008	320 ³	371 (2021-11-15 03:05)	
Nicola River at 08G0061 ¹	484 ³	373 (2021-11-15 10:15)	

¹Station failed during flood

²Ecora 2020

³Nichols et. al. 198

It was noteworthy that the hydrometric gauge on the Nicola River failed during the flood event and therefore the peak instantaneous flow for the event was not recorded at this location. Figure 5 indicates the locations of the hydrometric stations.

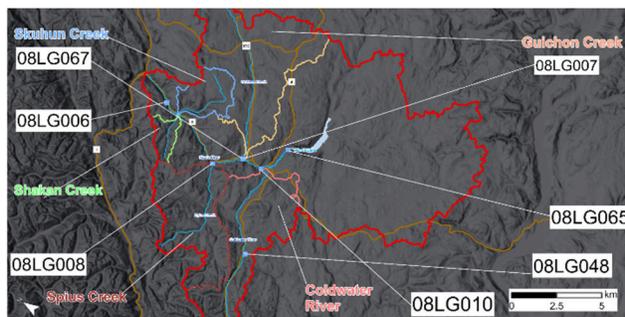


Figure 5. Approximate Locations of Hydrometric Stations.

4 RESULTING FLOOD DAMAGE

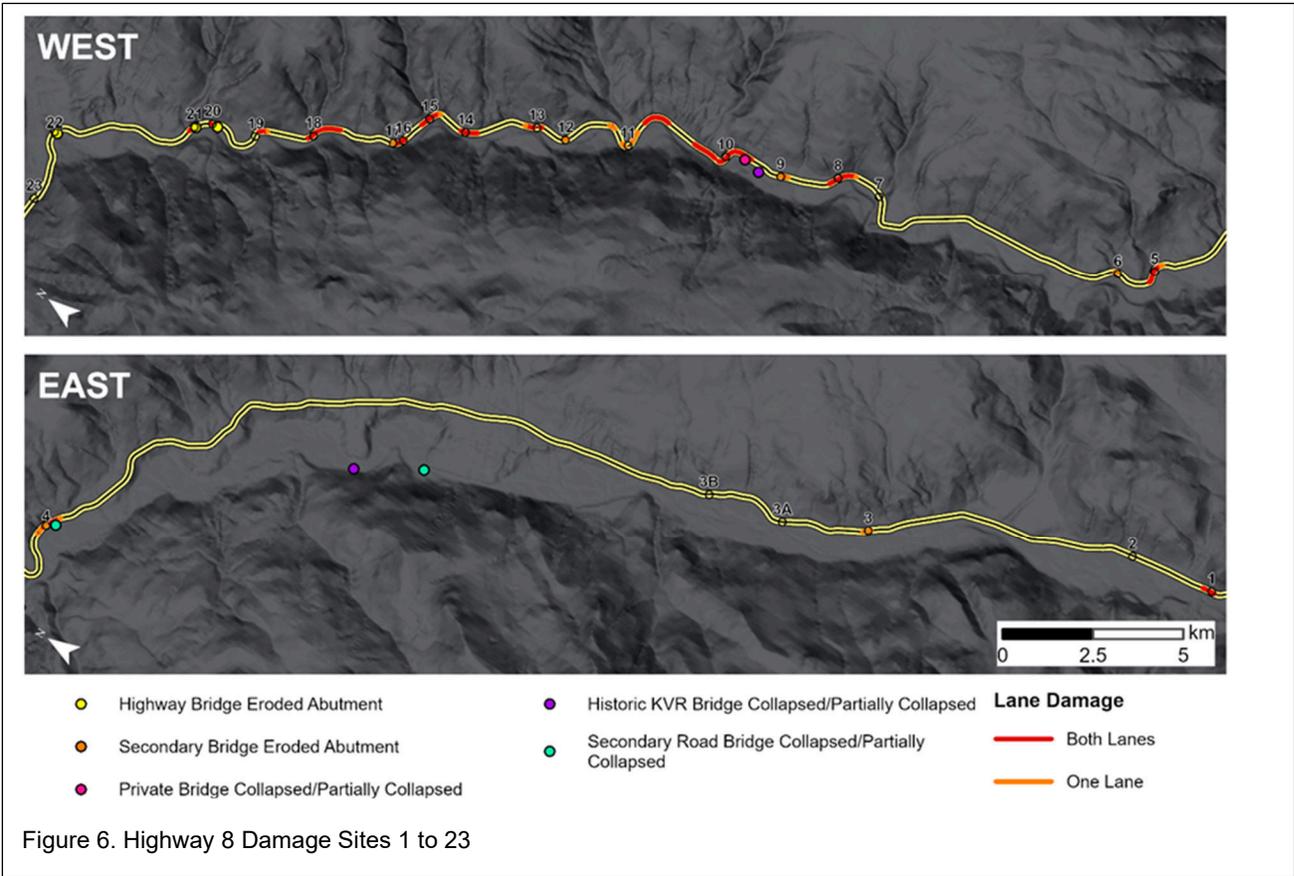
4.1 Site Overview

As a result of the November 2021 flooding event, 25 separate damage sites occurred on the Highway 8 corridor between Merritt and Spences Bridge, BC. The 25 sites occurred over an approximate distance of 41 km between Sites 1 and 23. All 25 Hwy 8 sites occurred downstream of the Spius Creek confluence, suggesting that Spius creek flows during the event may have contributed to the subsequent downstream damage. Locations of each site are depicted on Figure 6.

Of the 25 sites, 22 involved damage to the Hwy 8 road embankment structure (erosion/scour) while 3 involved damage to Hwy 8 bridge structures. Approximately 7km of 2 lane highway embankment structure and 1km of single lane (river side) were damaged, respectively. Table 2 provides a summary of the damage at each site and the approximate volume of eroded material (where calculated).

Table 2. Summary of Observed Damage

Site	Nature of Damage	Approximate Length of Highway Impacted (m)	Approximate Volume of Material Eroded (m ³)
Site 1	2 Lanes Eroded	210	52,500
Site 2	1 Lane Eroded	130	1,800
Site 3	1 Lane Eroded	150	
Site 3A	Shoulder Eroded	50	950
Site 4	2 Lanes Eroded	430	50,500
Site 5	2 Lanes Eroded	330	80,500
Site 6	1 Lane Eroded	70	26,600
Site 7	Embankment Toe Eroded	0	63,250
Site 8	2 Lanes Eroded	320	64,800
Site 9	2 Lanes Eroded	200	37,650
Site 10	2 Lanes Eroded	1000	403,650
Site 11	2 Lanes Eroded	1290	13,700
Site 12	2 Lanes Eroded	110	5,950
Site 13	2 Lanes Eroded	280	22,150
Site 14	2 Lanes Eroded	270	26,150
Site 15	2 Lanes Eroded	370	30,850
Site 16	2 Lanes Eroded	280	16,300
Site 17	2 Lanes Eroded	390	8,850
Site 18	2 Lanes Eroded	540	125,000
Site 19	2 Lanes Eroded	300	8,450
Site 20	Bridge Abutment Eroded	40	9,650
Site 21	Bridge Abutment Eroded	110	132,650
Site 22	Bridge Abutment Eroded	20	8,250
Site 23	Embankment Toe Eroded	0	52,500
Total Volume of Eroded Material (m ³):			1,242,650



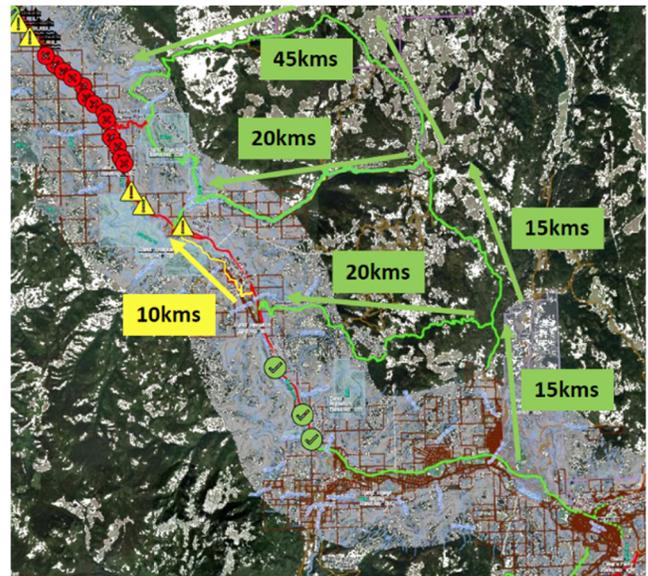
4.2 Site Access Limitations

Due to the linear nature of the Highway 8 corridor, very few parallel sideroads or secondary road networks exist that could provide alternative access beyond the damaged sections of highway. The south/west bank of the Nicola River does not have any secondary or resource roads that provide access to public roads outside of the Highway 8 corridor.

The north/east bank of the Nicola River has several FSR (Forest Service Roads) roads that provide connectivity between the Highway 8 corridor and Lower Nicola (via Aberdeen Rd). Several un-named, local/private roads were also identified on the lower reaches of the Nicola River that may provide some limited connectivity between the Highway 8 corridor and Highway 97C, however the status/condition was not generally suitable for travel.

At the time of the event in November 2021, the condition of the FSR's was generally not suitable for mainstream public travel, due to general inactivity in the forestry resource sector. One of the primary initial responses of the various agencies involved (BC Ministry of Transportation & Infrastructure, BC Ministry of Forests Lands Natural Resource Operations) was to re-establish reasonable connectivity to Highway 8 via these routes. The Gordon-Stumbles, Pimainus and Skuhun FSR's were restored/improved to provide initial connectivity to the Highway 8 corridor, with access to the Dot/Agate area and

Shakan First Nations, respectively. The use of these FSR's allowed for limited access to landowners/residents located between Sites 3 and 4 and the Shakan First Nations community, between Sites 4 and 5. Figure 7 depicts post-event access routes to the Highway 8 corridor.



4.3 Highway Embankment Damage (22 Sites)

Damaged highway sections consisted primarily of erosion due to elevated water levels/flows of the Nicola River. Most of the damage sites occurred where the Hwy 8 alignment was situated on outside bends of the Nicola River and in-situ soil conditions consisted of erosion prone soils. Sites 4, 5 (See Figure 8), 8, 10, 11, 13, 15 and 18 experienced significant erosional damage resulting in near vertical slopes ranging in height from 5 to 40+m.



Figure 8. Highway 8 – Site 5 Typical Erosion Damage.

4.4 Highway Structure Damage (3 Sites)

Three major highway structures were damaged due to the November 2021 event. All three structures were located on the lower reaches of the Nicola River and were of relatively recent (circa 1986) design and construction.

Three Mile, Rattlesnake and Curnow Bridges all suffered from abutment damage, with major scour and erosion of the approaches on all three structures. Three Mile and Rattlesnake bridges suffered significant erosional damage to the bridge approaches and scour of the abutments, while Curnow Bridge suffered mainly scour of the abutment. Figure 9 depicts structural damage.



Figure 9. Highway 8 – Site 21 Rattlesnake Bridge Approach and Abutment Damage.

4.5 LiDAR Change Detection

LiDAR (Light Detection and Ranging) remote sensing technology was used to detect damage that occurred due to the event. Flights conducted in November 2021, shortly after the event, were compared with the previous 2017 LiDAR and change detection analysis was completed. An example of this change detection is shown on Figure 10.

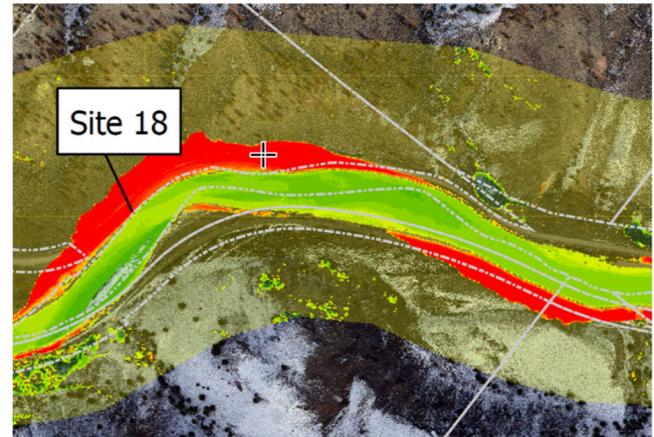


Figure 10. LiDAR Change Detection Results for Site 18. Red Denotes >3m of Vertical Change.

5 SUSCEPTIBILITY OF GLACIAL DRIFT TO EROSION

Significant erosional damage took place to the Highway 8 corridor downstream of the Gordon Creek tributary confluence, where the surficial geology consists of the Nicola Valley Complex and this segment contains numerous examples of glaciolacustrine terraces, scarps and glacial drift blankets of variable thickness.

The presence of glaciolacustrine deposits corresponds with the glacial-lake evolution stages of both Glacial Lake Thompson (high stage) and Glacial Lake Deadman (low stage), both of which extended partway up the Nicola River Valley from the confluence with the Thompson River (Johnsen et al. 2004). Figure 11 depicts the approximate extents of glacial lakes and ice formation.

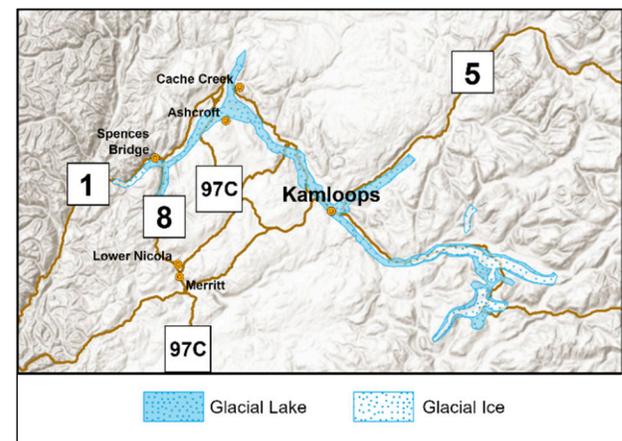


Figure 11. Approximate Extents of Glacial Lakes/Ice

The glacial drift and glaciolacustrine deposits are predominant at Sites 4, 5, 8, 10, 11, 13, 15, 18 and 21. The drift material generally comprises a wide variety of gravels and sands, interspersed with minor quantities of fine-grained materials. The glaciolacustrine deposits are predominantly sands and fine-grained materials and are typically located closer to the Nicola River confluence with the Thompson River.

Samples retrieved from these sites have been analyzed for grain size distribution and a summary is presented in Table 3.

Table 3. Summary of Grain Size Distribution for Sites Comprising Glacial Drift and Glaciolacustrine Deposits

Site	% Gravel (4.75 to 75mm)	% Sand (0.075 to 4.75mm)	% Silt/Clay (<0.075mm)
Site 4	48.3	35.7	7.9
Site 5	7.0	90.6	2.4
Site 8	9.8	88.5	1.7
Site 10A	71.9	26.7	1.4
Site 10C	3.7	93.2	3.1
Site 18	22.8	59.4	13.9
Site 21A	44.1	32.2	16.6
Site 21B	30.4	30.2	39.4
Site 21C	34.2	52.4	13.4

6 INFLUENCE OF HYDRAULIC RESTRICTIONS

The damaged through the corridor was significantly amplified in areas due the presence of natural and artificial hydraulic constrictions in proximity to the glacial drift deposits that are vulnerable to erosion along sections of the Nicola River.

Natural restrictions typically comprised bedrock outcrops that either directed flow to the opposing bank and/or restricted flows creating a backwater affect thereby increasing flow velocity immediately downstream of the restriction.

Artificial restriction typically comprised bridges with insufficient hydraulic capacity to pass the peak flood flows. Field observations at bridge locations noted a backwater affect with silt deposition from a pronounced lake immediately upstream of several bridge crossings. Inferred high water observations indicated that maximum flow depths reduced over 1.0 m immediately downstream of several destroyed bridge crossings.

The magnitude of flood damage observed immediately downstream of several destroyed bridge crossings suggests that a peak flow (pulse) potentially greater than that generated by runoff due to bridge may have occurred and that cascading failure of several bridges may have occurred. Figure 12 depicts silt deposition upstream of a pre-event bridge crossing.



Figure 12. Highway 8 – Site 4. Silt Deposition Indicating Backwater Affects Due to Upstream Bridge.

6.1 Example of Natural Hydraulic Restriction - Site 7

The erosional damage at Site 7 was influenced by a natural rock outcrop present in left bank of the river at the upstream end of the site which restricted and deflected flows towards the right bank as depicted on Figure 13.



Figure 13. Highway 8 – Site 7. Example of Natural Hydraulic Restriction.

6.2 Example of Artificial Hydraulic Restrictions – Site 10

At the upstream end of Site 10 an old railway bridge associated with the Kettle Valley Railway was present prior to the flood with a maximum opening of approximately 50 m. During the flood the left abutment was undermined causing a jump span to collapse. The resulting flood wave eroded the left abutment back approximately 60 m increasing the river width to approximately 110 m at this location. Figure 14 illustrates the former location of the railway bridge and subsequent erosion.

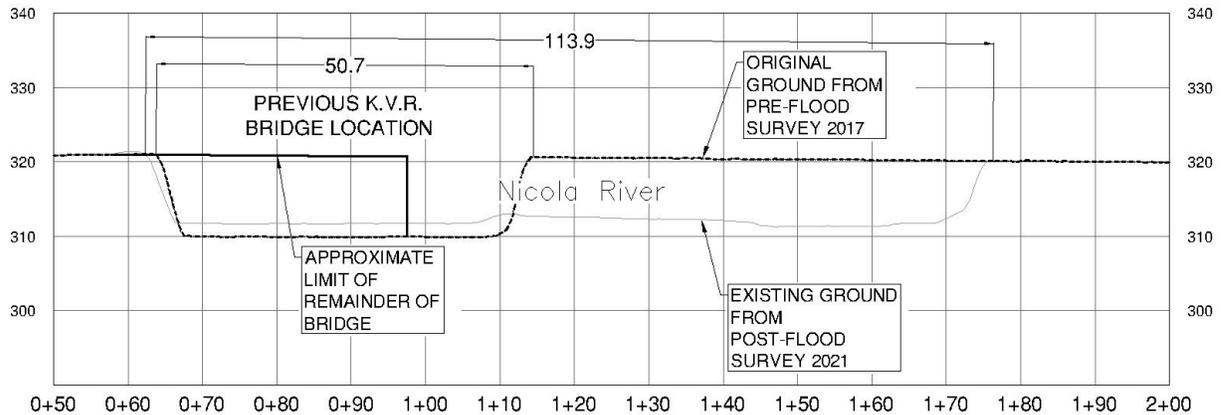


Figure 14. Highway 8 – Site 10 Section Through KVR Bridge

7 GEOHAZARDS RESULTING FROM FLOOD DAMAGE & IMPACTS ON RESPONSE WORKS

7.1 Examples of Geohazards Resulting from Flood

The resulting flood damage created multiple geohazards for the response team to contend with including some significant landslide hazards that in one extreme case (Site 10) resulted in an approximately 3 km section of the highway being temporarily shifted onto the historic Kettle Valley Railway alignment on the opposite side of the river.

Most of the erosion sites have slope instability hazards comprising either sections of undermined and over steepened highway embankment and/or significantly eroded slopes forming escarpments above the highway alignment. Figures 15 and 16 depict a typical example of undermined highway embankment and escarpment formation, respectively.



Figure 15. Highway 8 – Site 5. Example of Undermined Section of Highway Embankment.

Increased rock fall exposure was encountered at several sites due to the erosional damage shifting construction access towards existing rockfall hazard zones, or the deposition of material during peak flood flows.

Several small debris flows associated with seasonal drainage features and groundwater seepage were encountered in areas with loose glacial drift colluvium.



Figure 16. Highway 8 – Site 10. Example of Escarpment Formation Above Highway Alignment and Small Debris Flow.

7.2 Geohazards Impacts on Response Works

Where possible, the highway response works were constructed along the pre-flood highway alignment, however this was not always considered feasible at some sites due to the presence of the geohazards created by the flood. Where significant landslide hazards were present the response works were constructed using a safe set forward distance from the hazardous slopes based on determining the long-term angle of repose of historical slope performance from the pre-flood LiDAR. An example of safe set forward distance is depicted on Figure 17.

However, in the case of Site 10, the safe set forward distance from the escarpments formed by the flood would require the highway to be relocated down the center of the Nicola River and therefore the project team made the

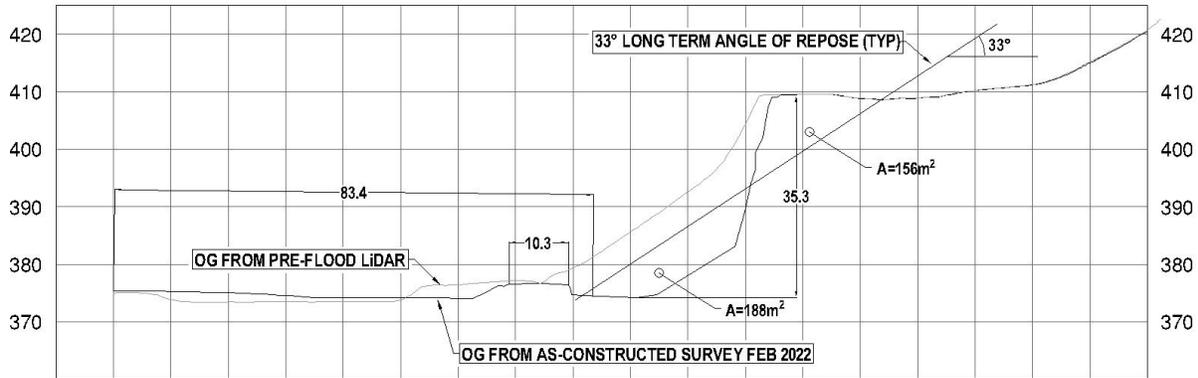


Figure 17. Highway 8 – Site 5. Example of Determining Safe Set Forward Distance from LiDAR.

decision to shift the temporary highway alignment to the abandoned Kettle Valley Railway corridor along the left back of the Nicola River. During construction of the response works, several post flood landslides were observed within the glacial drift escarpments, with one notable slide observed on February 5, 2022 within Site 10 and illustrated (inset) on Figure 18.



Figure 18. Highway 8 – Site 10. Landslide February 5, 2022.

8 CONCLUSIONS

The magnitude and scale of the damage caused throughout the highway 8 corridor due to the November 2021 atmospheric river event highlights that, the vulnerability of soils to erosion needs to be considered when undertaking flood risk assessments where soil and geomorphological conditions are susceptible to erosion. The effects of hydraulic constrictions, backwater effects and pulses due to structural failure should also be considered when determining peak instantaneous flows and a system wide approach to flood risk assessments may be necessary in similar geological and geomorphological environments.

The identification and understanding of known pre-flood and post-flood geohazards are critical in developing appropriate flood response works. Due to the relatively rapid nature of flood response construction works, the availability of pre-flood and post-flood LiDAR data is a valuable tool in assessing the impacts of geohazards on response works.

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