Analysis of a British Columbia Resource Road's Vulnerability to Climate Change:

in-SHUCK-ch Forest Service Road PIEVC case study

Technical report no. 30 – June 2018

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Abstract

This report presents a case study of the vulnerability to climate change of infrastructure on the in-SHUCK-ch Forest Service Road using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol. This case study provided analysis of the risks and opportunities faced by the road, recommendations to mitigate the identified risks, and established a benchmark for future iterations of the process with resource roads.

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1. Executive Summary

British Columbia has very varied and complex geography and the predicted climate changes over the Province are equally complex and varied. Climate change models for B.C. predict that by the 2050s the mean annual temperature will increase by 1° to 4° C. Along with the increased temperatures, it is anticipated there will be a marked contrast between wet and dry seasons, along with increased frequency of extreme precipitation events and periods of hot dry weather. Regionally in B.C., it is expected that winters will be up to 20% wetter; and summers will be up to 15% drier in the south and 10% wetter to 10% drier in the north. There also will be an increase in precipitation intensity.

As the effects of climate change begin to impact the natural resources that are integral to the prosperity of British Columbians, planning and implementation of climate change action, such as this analysis, will become common in the resource sector. As such, the Climate Change Strategy of the B.C. Ministry of Forests, Lands and Natural Resource Operations & Rural Development (FLNRORD) identified the need to integrate climate change adaptation into its core business, beginning with decision makers and staff viewing projects through a climate change mitigation reduction lens (FLNRO 2013). Moving forward with the process, decision makers will be able to identify thresholds for climate change action and the economic consequences of reactionary versus precautionary action.

A variety of methods are available to assess the vulnerability of engineered structures to climate change, however, the method most commonly used in Canada is the PIEVC protocol. The PIEVC protocol is a civil engineering tool specifically created to assess infrastructure vulnerability to extreme weather events and other climate changes.

In 2015, FLNRO, with technical assistance from the B.C. Ministry of Transportation and Infrastructure, conducted a workshop to use the PIEVC protocol to assess the vulnerability of a resource road (and associated road corridor) to climate change. The subject of this pilot case study was the in-SHUCK-ch forest service road (FSR) and corridor which runs southward for 70 km beside Lillooet Lake and Lillooet River starting near Pemberton, B.C. and ending at the north end of Harrison Lake. FPInnovations was asked to attend, contribute to, and document the case study. This case study provides a benchmark for future iterations of the process, and provides meaningful analysis of the risks and opportunities faced by the in-SHUCK-ch FSR corridor and the communities it provides access to.

Riparian habitat and debris flow routes, landslide prone areas, and culverts along the in-SHUCK-ch FSR corridor were predicted to be highly vulnerable to prolonged dry periods and high temperature extremes. Bridges, culverts, ditches, and cut slopes were predicted to be highly vulnerable to extreme rainfall events.

A series of recommendations are made that arise from the PIEVC analysis. These recommendations include the need to streamline and focus the PIEVC process specifically for resource roads, capacity building actions by road managers and maintainers, a review of emergency preparedness plans for the First Nations communities at the south end of the FSR, actions to safeguard FSR infrastructure and residential development on lakeshore debris fans, a general review and inspection of drainage structures, actions to review and improve the resiliency of stream crossing structures and, finally, a recommendation to review the scope and size of the road maintenance program.

2. Introduction

In 2015, the B.C. Ministry of Forests, Lands and Natural Resource Operations (FLNRO) with assistance from the B.C. Ministry of Transportation and Infrastructure (MOTI), conducted a workshop to use the PIEVC protocol to assess the vulnerability of a resource road (and its corridor) to predict climate changes (Bradley 2015). The project team is described in Appendix B. The subject of this pilot case study was the in-SHUCK-ch forest service road (FSR), which is located northeast of Vancouver, B.C. This road was selected because it had experienced recent failures due to extreme weather events, and it had recently been upgraded to improve the reliability of access to First Nations communities and subjected to a comprehensive LiDAR survey.

As the effects of climate change begin to impact the natural resources that are integral to the prosperity of British Columbians, planning and implementation of climate change action, such as this analysis, will become common in the resource sector. As such, FLNRO's Climate Change Strategy has identified the need to integrate climate change adaptation into its core business, beginning with decision makers and staff viewing projects through a climate change mitigation reduction lens. Moving forward with the process, decision makers will be able to identify thresholds for climate change action and the economic consequences of reactionary versus precautionary action. British Columbia has very varied and complex geography and the predicted climate changes across the Province are equally complex and varied. This variation presents a significant obstacle for those seeking to derive one set of climate change guidance and policy for the entire Province. This case study provides a benchmark for future iterations of this process, and provides meaningful analysis of the risks and opportunities faced by the in-SHUCK-ch FSR corridor and the communities it provides access to.

Project objective

The objectives of this project were to develop and test an approach for assessing the resource road vulnerability to climate change on an FSR in coastal B.C., and to determine what general conclusions about resource road vulnerability could be derived from the analysis.

Notice to reader

Most of the PIEVC process was followed, with some deviations, during the vulnerability assessment workshop. The adaptation of a B.C. highway PIEVC template to suit B.C. resource roads was a novel process and sorting through the large number of possible interactions of climatic parameters and infrastructure elements (884 interactions) was time consuming. Participants were able to discuss and assign risk ratings to about 40% of these interactions within the allotted time. The workshop was extended by one day to provide participants with more opportunity to complete the process, however, some interactions remained unconsidered or unrated by its conclusion. Perhaps more importantly, participants did not consider predicted changes to climatic parameters (climate changes) and how these were likely to impact FSR infrastructure. In order to complete the assessment, FLNRO expanded the role of FPInnovations from that of merely observing and documenting the PIEVC process to one in which FPInnovations also completed the risk ratings, largely based on its own technical expertise. This process deviation delayed the completion of the project and may have limited the insight and development of the report recommendations.

Climate change in British Columbia

Climate change models for B.C. predict that by the 2050s the mean annual temperature will increase by 1° to 4° C (Figure 1). Along with the increased temperatures, it is anticipated there will be a marked contrast between wet and dry seasons, along with increased frequency of extreme precipitation events and periods of hot dry weather. Regionally in B.C. it is expected that winters will be up to 20% wetter; and summers will be up to 15% drier in the south and 10% wetter to 10% drier in the north. There also will be an increase in precipitation intensity (Spittlehouse 2010).

Data sources

Pacific Climate Impacts Consortium (PCIC) Plan2Adapt site, based in Victoria, has predicted climate changes based on western Canadian data whereas another popular Canadian climate change prediction site, Ouranos, utilizes eastern Canadian data. It is important to understand what the data is and where it is from before working with predictions. PCIC has free, online, short courses for understanding climate data on their website. PCIC can be accessed at http://www.pacificclimate.org/ and Ouranos can be accessed at http://www.ouranos.ca/en/ .

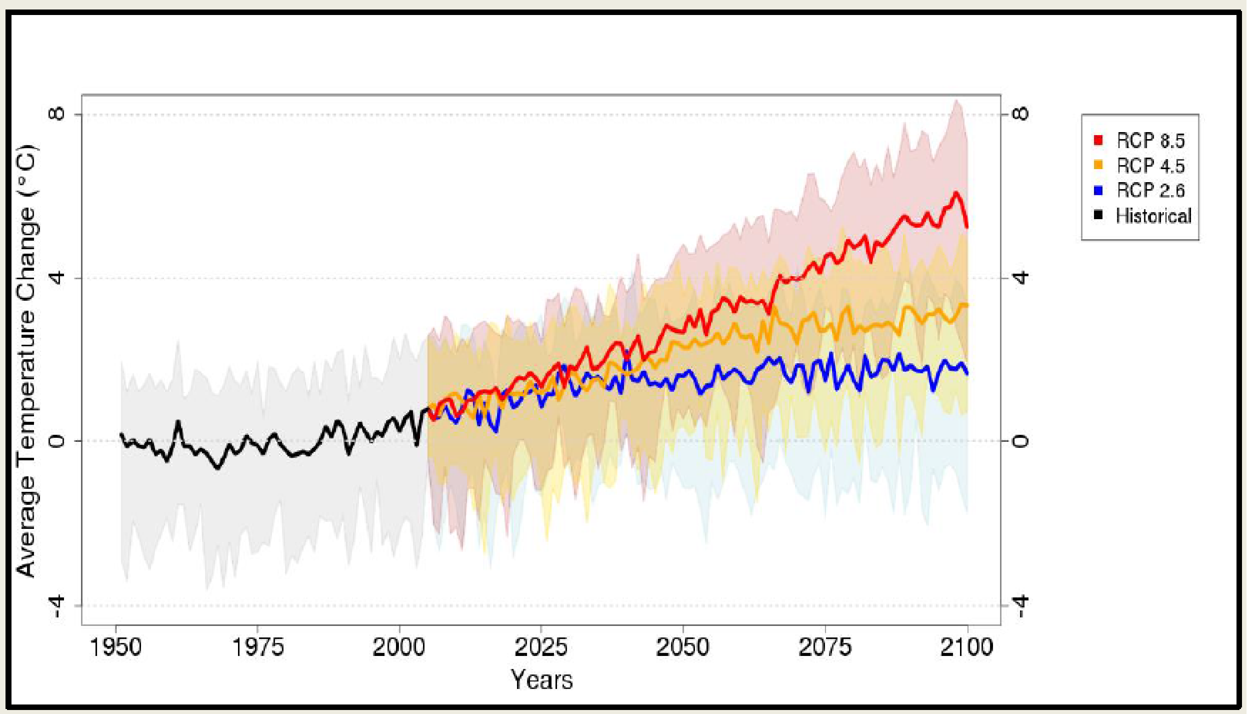

Figure 1. Average warming predicted for B.C. over this century (Spittlehouse 2015b).

Analysis of infrastructure vulnerability to climate change

A variety of methods are available to assess the vulnerability of engineered structures to climate change, however, the method most commonly used in Canada is the PIEVC protocol. The PIEVC website has over 40 case studies of a variety of types of structures. At its core, the PIEVC protocol is a civil engineering tool used to assess climate vulnerability and extreme weather events on infrastructure.

MOTI is already using the PIEVC protocol, and has been actively working with Engineers Canada, the Pacific Climate Impacts Consortium and the Association of Professional Engineers and Geoscientists of British Columbia to adapt design criteria and construction practices to reflect the predicted effects of climate change, information regarding this process can be found on the MOTI “Adapting to Climate Change” website at http://www2.gov.bc.ca/gov/content/transportation/greening-transportation/climate-action/adaptation.

Data requirements. A variety of data are required to conduct a vulnerability analysis. These include but may not be limited to: infrastructure age, condition and inspection data; traffic volumes; geotechnical and terrain information; extreme weather event data and its impact on infrastructure.

3. Site description

The in-SHUCK-ch FSR corridor is approximately 70 km long with KM numbering starting from the north end at the FSR intersection with Highway 99 (Figure 2) (Figure 3).

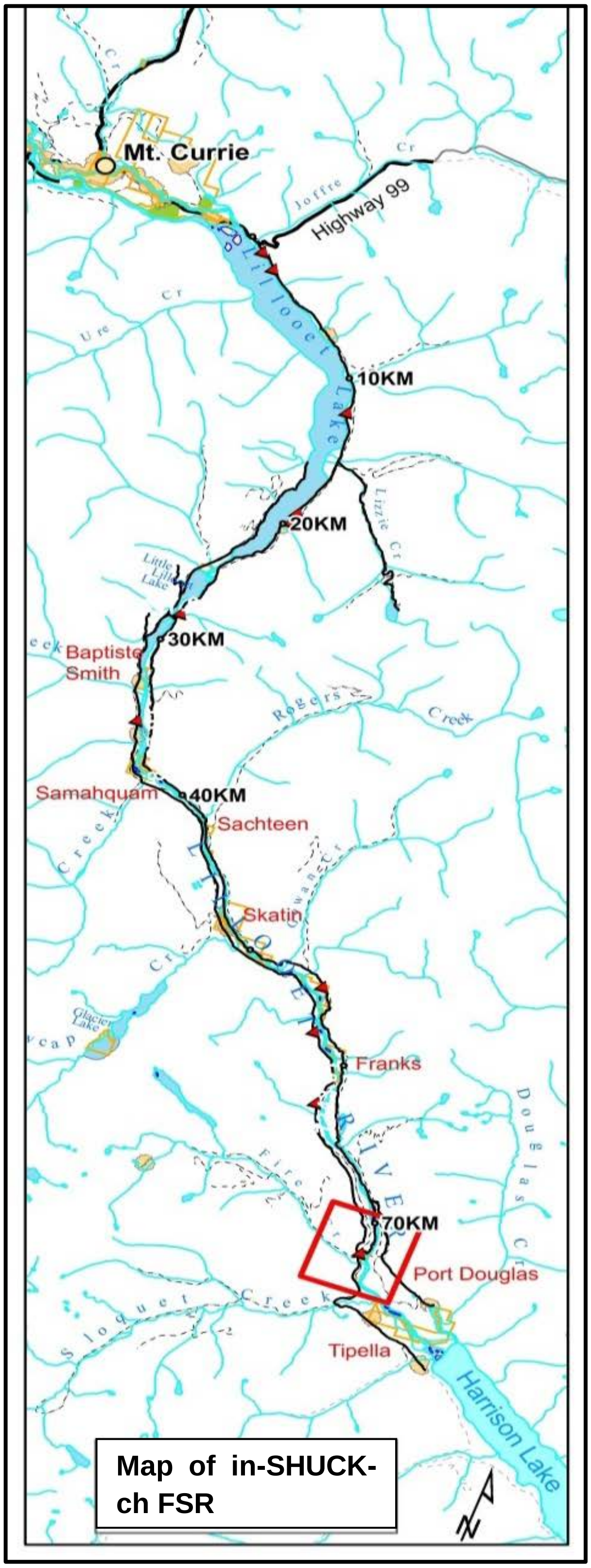

Figure 2. (Right) Map of the in-SHUCK-ch FSR (red triangles denote recreational sites). (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

Figure 3. (Above Left) The in-SHUCK-ch FSR intersects Highway 99 at 0 KM at the north end of Lillooet Lake. The Lillooet River has a wide delta there and surrounding terrain is steep and mountainous. (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

The terrain of the in-SHUCK-ch FSR corridor is mountainous and drops in elevation from north to south. Due to the steep terrain, the FSR closely follows the eastern shore of Lillooet Lake and the Lillooet River. Originally built as a powerline right-of-way to the lower mainland (Figure 4), the FSR now provides access to First Nations and resort communities, managed forests, recreational areas, and independent power projects (near Port Douglas). A number of resort communities and recreation sites along the corridor are located on lakeshore alluvial fans fed by steep mountain streams (e.g., Strawberry Point (near KM 6), Lillooet Lake Lodge (near KM 12), and Lizzie Bay (near KM 15). Fourteen First Nations reserves are located beside Little Lillooet Lake and the Lillooet River between KM 25 and KM 70, often at the confluence of side drainages with the Lillooet River (Paqulh, Challetkohum, Baptisite Smith, Q'alatkú7em, Samahquam, Sachteen, Sweeteen, Skookumchuck (called Skatin in the St'at'imcets language), Morteen, Sklahhesten, Franks, Perrets, Lelachen, Douglas, and Tipella).

Figure 4. The in-SHUCK-ch FSR follows the path of power lines south to Port Douglas (left). A bridge joins the in-SHUCK-ch FSR with the Lillooet West FSR near the inlet to Little Lillooet Lake (KM 34). (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

The in-SHUCK-ch FSR follows the east shore of Lillooet Lake, Little Lillooet Lake, and Lillooet River south to Port Douglas; the Lillooet West FSR follows the west shore of Little Lillooet Lake and Lillooet River south towards Port Douglas and then down the west side of Harrison Lake to Agassiz in the Fraser Valley (Figure 5) Two bridges, located near KM 34 and near KM 71, cross the Lillooet River to connect the two roads. Portions of the Lillooet West FSR immediately south of Port Douglas are rough, steep, narrow, and this restricts road access to the communities from the south. Small boat services, however, do connect the communities on Harrison Lake.

Figure 5. Near KM 70 of the in-SHUCK-ch FSR, the Lillooet River enters a large delta at the north end of Harrison Lake. (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

Recent weather-induced damage

Climate-related issues along the in-SHUCK-ch FSR have included flooding near KM 24 at the outlet from Lillooet Lake, and ice flows and ice falls onto the road near KM 1 (Figure 6); culvert washouts and bridge undercutting by high stream flows (Figure 7); debris torrents (Figure 8); rock and water falls onto the road surface; and, narrowed road width due to fill slope failures (Figure 9). Wildfires in the surrounding area also are a concern as they may increase flash flooding and woody debris in streams. Increased erosion problems and slope failures after wildfires have occurred elsewhere in B.C. since 2003 (Bradley 2015). In 2014-2016, capital projects raised the FSR roadbed on flood plains subject to flooding near KM 24, widened the roadway, and improved alignment, where needed (Figure 10).

Figure 6. Flooding of the FSR at the south end of the Lillooet Lake (left), and ice flows down rock cuts and onto the FSR cause dangerous driving conditions (right). (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

Figure 7. Large culvert washout (left) and bridge abutment undercutting (right) caused by high stream flows. (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

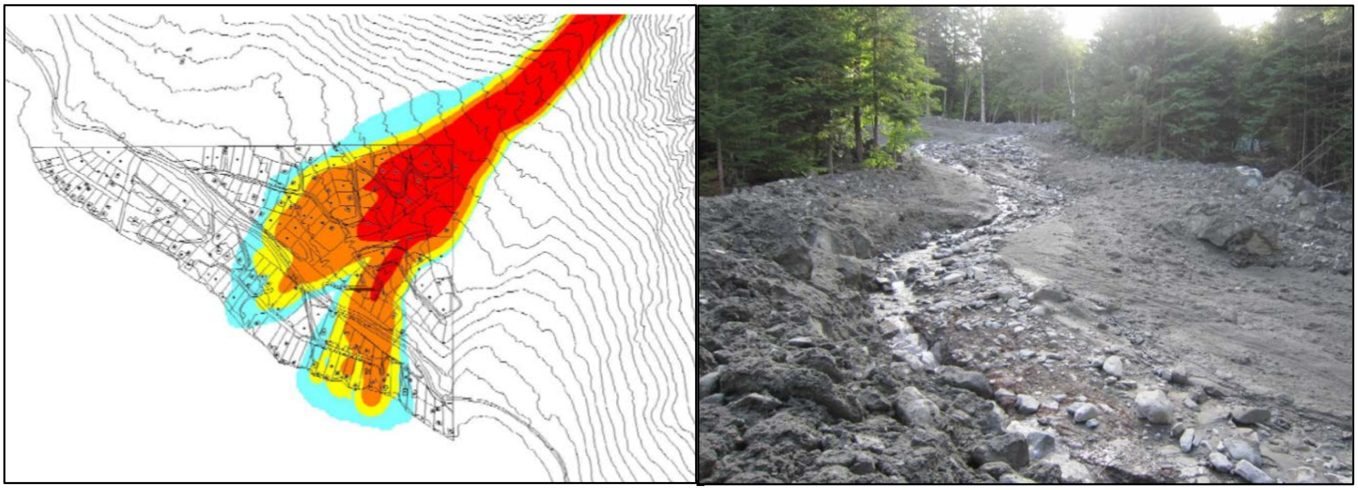

Figure 8. Looking upstream (left) and colour-coded survey (right) of a debris torrent at Heather Jean Estates. (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

Figure 9. Rocks and water fall onto the in-SHUCK-ch FSR (left), and narrowed road width due to fill slope failures (right). (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

Figure 10. Recent capital projects raised previously flooded roadbed near KM 24 (left) and widened narrow sections of roadway (right). (Source: FSR overview presented at in-SHUCK-ch PIEVC workshop, Squamish, B.C.).

Climatology predictions

Spittlehouse (2015) summarizes historical and predicted future climatology for the in-SHUCK-ch FSR. Historical weather patterns of the Lillooet Valley were characterized through an evaluation of historical daily gridded BCCAQ data interpolated between four nearby climate stations (Cayoosh Summit 1979 – 2014), Cheakamus Upper, Stave Upper, Whistler climate stations) and with monthly values from ClimateBC data. The focus was on climate normals, distributions, and extremes. Where necessary, the BCCAQ data was downscaled to a finer grid.

The period 1971-2000 was taken to be a reference baseline, and climate predictions were developed for the periods 2011-2040, 2041-2070, and 2071-2100. Predicted climate trends were summarized from the results of modelling using 12 different climate change models, and two greenhouse gas emission scenarios (rcp 4.5 and rcp 8.5 (the status quo scenario)). Figure 11 illustrates the historic (1971-2000) distribution of total annual rainfall in the in-SHUCK-ch FSR area.

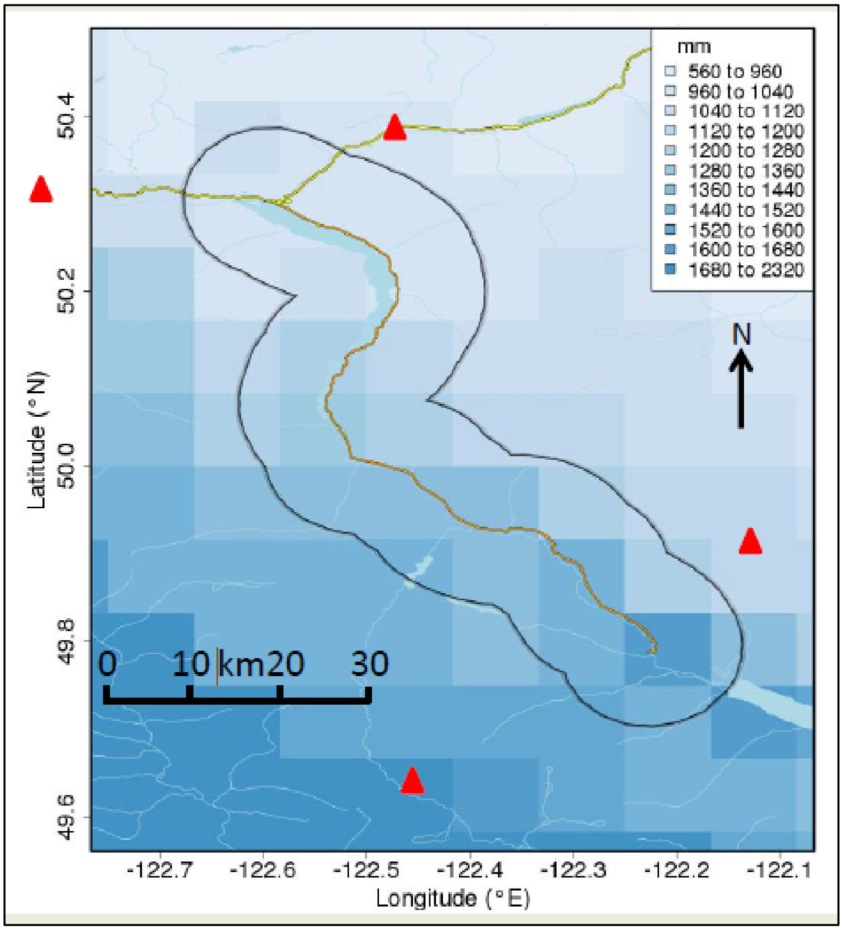

Figure 11. Historical annual precipitation in the in-SHUCK-ch FSR corridor (Spittlehouse 2015).

Table 1 summarizes the mean annual precipitation change anticipated for rcp 8.5 (no change to current greenhouse gas emission levels). Use of 12 climate models to make these predictions resulted in a relatively large amount of variation (i.e., ±6% to ±25%). Under this emission scenario, it is predicted that by 2041 winters will have 0% to 12% more precipitation (6% more, on average), in the form of rain. Summers are predicted to have 1% to 31% less rain (16% less, on average). Changes are expected to continue for the period 2071 to 2100. By 2071, it is predicted that winters will have 2% to 26% more precipitation (14% more, on average), and summers 1% to 31% less rain (16% less, on average). These changes in precipitation are expected to increase winter peak storm flows and to shift peak flows to earlier in the year; summer low flows may further decrease.

Table 1. In-SHUCK-ch FSR changes in mean seasonal precipitation rom 1971-2000 levels to 2041 (rcp 8.5 projections) (Spittlehouse 2015)

Period	Winter	Summer
2041-2070	+6% (±6%)	-16% (±15%)
2071-2100	+14% (±12%)	-25% (±25%)

Table 2 summarizes the predicted changes in annual and storm precipitation anticipated for rcp 8.5. The average annual rainfall for the FSR area was 1510 mm during the historic reference period but is predicted to increase to 1630 mm in the near future. By 2041, mean annual precipitation is predicted to increase by almost 8% and the intensity of 20-year return period 1-day and 5-day storms by 16%. In the distant future, mean annual precipitation and 20-year storm intensity are predicted to almost stabilize by 2071 with minimal increases predicted to 2100.

Table 2. In-SHUCK-ch FSR historical and predicted mean annual and storm precipitation (rcp 8.5 projections) (Spittlehouse 2015)

	1971-2000	2041-2070	2071-2100
Mean annual precipitation (mm)	1510	1630	1670
1-day maximum with 20-year return period (mm)	90	105	105
5-day maximum with 20-year return period (mm)	180	210	220

Table 3 summarizes historical and predicted temperature extremes in terms of 20-year return period extremes. By 2041, extreme summer highs are predicted to increase by 15% and extreme winter lows to increase by 19% (from -32° to -26° C). These predictions were relatively consistent between the 12 climate models (i.e., varying by only ±2° to ±4° C). As with the precipitation, the rate of change in mean annual maximum and minimum temperatures is predicted to slow for the period of 2071 to 2100.

Table 3. In-SHUCK-ch FSR 20-year return period temperature extremes (rcp 8.5 projections) (Spittlehouse 2015)

	1971-2000	2041-2070	2071-2100
Maximum temperature	34° C	39° C (±2° C)	41° C (±3° C)
Minimum temperature	-32° C	-26° C (±3° C)	-22° C (±4° C)

Figure 12 illustrates the mean annual temperature extremes for the in-SHUCK-ch FSR area during the historical reference period (1971–2000). Temperatures in the north were slightly cooler in both summer and winter. Warming of 3° to 6° C is predicted for the area, on average, by 2100. Warming will increase the ability of air currents to carry moisture and this is expected to result in more precipitation and higher storm flows.

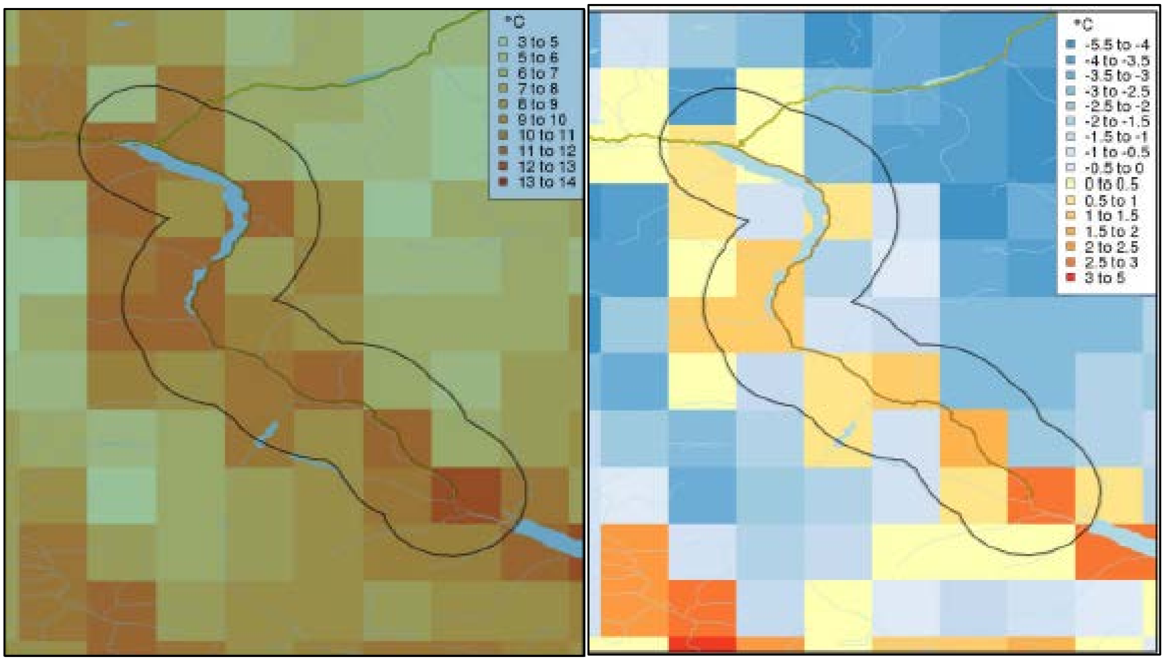

Figure 12. Historical (1971 to 2000) mean annual maximum (left) and minimum (right) temperatures in the in-SHUCK-ch area (Spittlehouse 2015).

Winters are predicted to have 6% more precipitation, on average, in the form of rain which may lead to reduced snowpack accumulation and more rain-on-snow events late in the winter. Figure 13 and Figure 14 illustrate the predicted influence of warming on winter snowfall. The number of heavy snowfalls is predicted to steadily decline from 1950 to 2097 (for the in-SHUCK-ch FSR area a 'heavy' snowfall is one that exceeds 100 mm per 24 hours). A dramatic reduction in the number of snow events and snow storm intensities (i.e., the occurrence frequency) are predicted in the future.

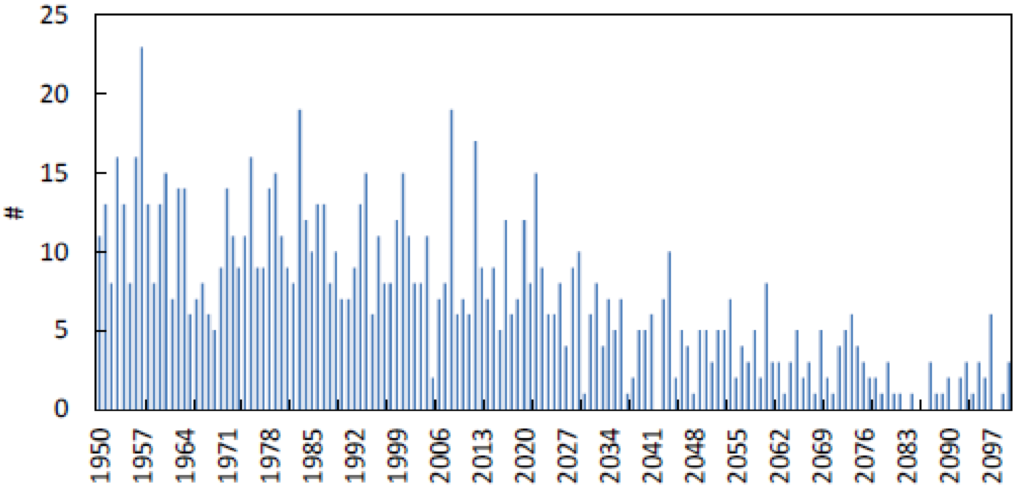

Figure 13. Historical and predicted number of snowfall events exceeding 100 mm per day (rcp 8.5 projections) (Spittlehouse 2015).

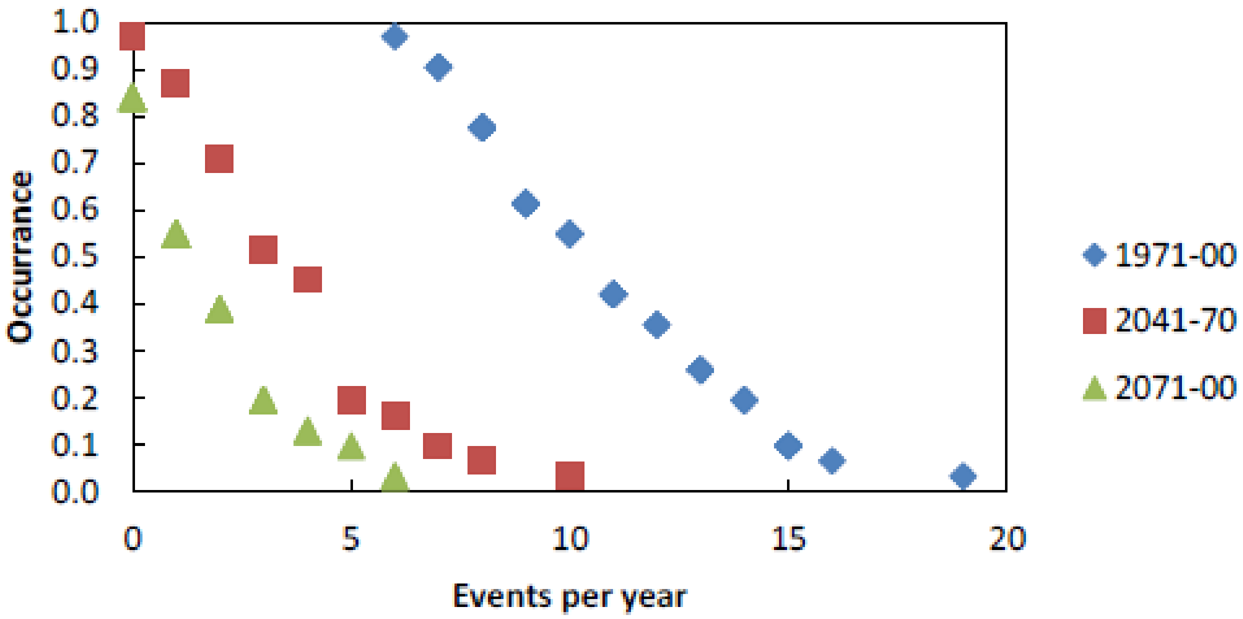

Figure 14. The number and intensity of snow events are predicted to decrease dramatically from historical levels (rcp 8.5 projections) (Spittlehouse 2015).

In summary, climate change projections predict a continuation of trends seen in the last century. Further warming, of from 3° to 6° C, will occur over this century. Precipitation changes will occur with there being more rain in the late fall, winter, and spring; longer hot and dry periods will occur in the summer. There will be an increase in temperature and precipitation extremes. There may be a heightened risk of wildfire, especially at the northern end of the watershed, and especially in August. Finally, there will be a substantial decrease in snow cover. The in-SHUCK-ch FSR area is a hybrid of snow-dominated and rain-dominated systems but, with future warming, the area will move towards a rain-dominated system.

4. PIEVC analysis of the in-SHUCK-ch FSR corridor

Analysis process

The protocol is a 5-step process to analyze the engineering vulnerability of an engineered structure (e.g., a building or a road infrastructure) to current and future climate parameters such as prolonged dry periods or extreme rainfall. The 5 steps of the protocol are: project definition; data gathering and sufficiency check; risk assessment; engineering analysis (if judged necessary for highly vulnerable items); conclusions and recommendations (Figure 15).

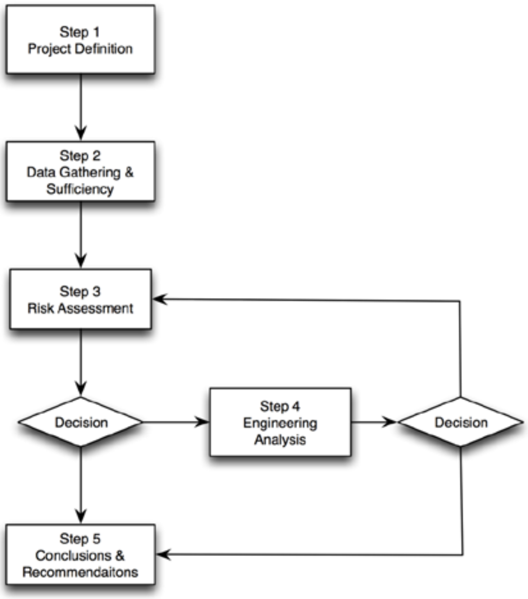

Figure 15. General flow chart for the PIEVC process.

In the data gathering and sufficiency step, it is important to consider which road infrastructure components to gather data on (e.g., bridges, road surfacing, cut slopes), which climate parameters are important, and how these climate parameters are likely to influence the road infrastructure components (Nyland 2016).

The assessment of the in-SHUCK-ch FSR corridor and surrounding terrain for vulnerability to climate change included numerous types of road infrastructure components: 17 road components, 5 third party utilities, 8 environmental features, and 4 miscellaneous items (see Appendix A). The following are specific examples of components of the in-SHUCK-ch FSR and its corridor that were specifically considered in the assessment:

1. Archaeological sites. 6000 - 9000 year-old archaeological sites and burial sites exist near or within the road right-of-way.
2. Flood plains. Flood plains on Lillooet Lake are subject to rises in lake level; debris fans project into Lillooet Lake with avulsions (channel changes). Sections of the FSR, including some bridges, are located on these vulnerable terrain features.
3. Riparian habitat. Riparian habitat, created in compensation, needs to be preserved.
4. Power lines and towers. Hydro transmission towers are in the FSR right-of-way; line sag increases with warmer temperatures and with ice build-up and this sag may critically reduce vehicle clearance.
5. South facing rocky hill slopes. High temperatures and sustained periods of heat (>25° C) and dryness (30+ days) on rocky, south facing, hill slopes may lead to excessive dry ravelling. Considerable amounts of material also may erode during substantial rain storm following the dry periods. Prolonged hot, dry conditions can create hydrophobic soils, which reduces infiltration and may increase the speed and volume of runoff (flash floods).

For each type of road infrastructure, 26 different climatic parameters, and their predicted future levels were considered. Table 4 summarizes some of the most important climatic parameters and their relevance to the infrastructure components. Through the course of the PIEVC workshop it became apparent that most of the climatic parameters of concern were precipitation related.

Table 4. Specific climatic parameters

Climate parameter	Definition - threshold	Relevance to the infrastructure component
Days above a maximum temp	Days with Tmax > 35° C	Bridge design
Week-long maximum temp	Average Tmax during 7 day period	Measure of short term high temperature relevant to fire indices, landslide trigger
Continuous no. of days with Tmax below threshold	No. of 7-day periods with Tmax < -5° C	Ice build-up on rock faces resulting in rock and ice fall onto road. Ditch and culvert ice build-up
Daily temperature variation	Days with daily temperature variation > 25 °C	Relevance to bridges - thermal expansion/contraction (i.e., max temp design range is 104° C or 79° C, depending on superstructure type)
Prolonged dry conditions	Periods lasting > 30 days during which Tmax > 15° C and total precipitation < 2.5 mm	Wildfire hazard, increased runoff from hydrophobic soils, dusty conditions
Extreme high rainfall in 24-hour period	>20 year return period. 1-day rainfall > 60 mm in north and >80 mm in south.	High runoff, culverts and bridges damage or destruction, road surface damage or deterioration, safety
Sustained rainfall	3-day rainfall > 100 mm and >150 mm in the north and south, respectively. (20 yr return period)	High runoff, culverts and bridges damage or destruction, road surface damage or deterioration, safety
Antecedent rain followed by significant rain event	antecedent 14-day cumulative rainfall > 150 mm followed by 24 hour rainfall > 50 mm	High runoff and saturated soils, impacts to cut/fill slopes, landslides, culverts and bridges damage or destruction, road surface damage or deterioration, safety
Annual precipitation - north and south areas of road	Total annual precipitation (mm)	Water management
Rain on snow	Rain (50 mm in 24 hr) onto > 60 cm of 'ripe' saturated snow pack; freezing is greater on ridge tops.	High runoff, culverts and bridges damage or destruction, road surface damage or deterioration, safety
Rapid snow melt (not with rain)	snowmelt > 30 mm per day	Spring freshet conditions causing runoff and peak streamflow, culverts and bridges damage or destruction, road surface damage or deterioration, safety. Driver for lake levels during melt period.
Ice/ice jams	Observed frequency of ice jammed in the river	Road blockage and/or flooding, uncontrolled erosion, unplanned closures
Freeze-thaw events	Number of days when Tmax > 0° C and Tmin < 0° C	Measures how much frost growth will occur in subsoil, below foundations etc. Rock fall related to freeze/thaw (e.g., KM 1 on the in-SHUCK-ch FSR). Spring load restrictions caused by thaw weakening may impact industrial operations in early spring.

Table 5 summarizes the historical and future levels for these same climatic parameters predicted by Spittlehouse (2015). As previously noted, the warmer winters will shift from snow-dominated to rain-dominated and will have fewer freeze-thaw events. Late winter, spring and fall will experience more frequent, more intense, rain storms. Prolonged hot dry spells will become more common for late summer. Climate models are not currently able to predict the occurrence of some parameters that were, nonetheless, considered during the PIEVC analysis, notably low rainfall, snow storms/ blizzards, rain-on-snow events with high wind, sleet/hail, fog, high wind combined with rain, snow driven peak flow events, ice/ice jams, and ground freezing.

Table 5. Historical and predicted threshold values for various climatic parameters (Spittlehouse 2015)

Climate parameter	1971 - 2000	2001 - 2040	2041- 2070	2071- 2100
Days above 35° C	4 days per year, range 12 to 0 days	10 ±2 days	20 ±7 days	36 ±15 days
Week-long maximum temp	33° C, range 29° – 37° C	35° ±1° C	38° ±2° C	40° ±3° C
Daily temperature variation of more than 25° C	Once every 2 years, range 0 - 2 days	Once every 1.5 years, range 0 - 2 days	2 ±2 days per year	2 ±0.5 days per year
Continuous number of days with Tmax below -5° C	2 periods per year, range 0 – 7 periods	1.5 ±0.5 days per year	1.5 ±1 days per year	0 days per year
Prolonged dry conditions of 30+ days	Once every 2 years, range 0 - 60+ days	0.5 ±0.2 periods per year	1 ±0.5 periods per year	2 ±0.5 periods per year
Extreme high rainfall in 24-hour period	20 yr return period	10 ± 3 yr return period	7 ± 3 yr return period	4 ± 2 yr return period
Sustained rainfall	20 yr return period	20 yr return period	8 ± 4 yr return period	4 ± 2 yr return period
Antecedent rain followed by significant rain event – in north and south part of road	20 yr return period on north part; 2 to 4 yr return period on south part	15 yr return period on north part; 2.5 ± 1 yr return period on south part	10 yr return period on north part; 2 ± 1 yr return period on south part	5 yr return period on north part; 1 yr return period on south part
Annual precipitation – north and south areas of the road	1050 ±250 mm 1480 ±300 mm	1090 ±25 mm 1515 ±30 mm	1150 ±50 mm 1580 ±50 mm	1200 ±50 mm 1660 ±50 mm
Rain on snow	Rare, range 0 – 1 days per year	Rare	Rare	No events
Rapid snow melt (not with rain)	4 days per year (range 0 to 6 days)	4 ± 1 days per year	4 ± 1 days per year	3 ± 1 days per year
Freeze-thaw events	113 days per year (range 85 – 135 days)	90 ±9 days per year	75 ±9 days per year	50 ±9 days per year

Note: range values are for 10th and 90th percentile values

The probability of the climatic event occurring, and the severity of damage to the road infrastructure component caused by its occurrence, was estimated using both the Spittlehouse (2015) climatology predictions and local experience. In the risk assessment step, climatic factors for the resource road are developed based on the watershed, location within the watershed, temperatures, etc. Climatologists input these factors, with assumptions for various climate change scenarios, into climate prediction models to make both regional and down-scaled, localized, climatic predictions. These predictions are then used to identify trends and general results.

A high level risk assessment was made for each infrastructure component identifying which, and by how much, climatic parameters were likely to influence the performance of each infrastructure component. A spreadsheet table was used to organize and calculate the risk assessment score for each combination of infrastructure component and climatic parameter. This was calculated using the probability rating of the predicted climatic parameter (low, medium high), and a severity rating (Equation 1). The risk rating took into consideration whether the infrastructure would lose its functionality or if a public safety hazard would be created by the climate parameters occurrence.

Equation 1. Risk of climate change-induced damage to an infrastructure component

$$Risk\ Assessment\ Score = Probability\ of\ Occurance\ x\ Severity\ of\ Occurance$$

Risk assessment score	Recommended action
0 to 15	No further consideration needed
16 to 30	Further consideration
30 to 49	Engineering analysis by designer

Probability scoring was as follows: low probability had a score of 3, medium probability had a score of 6 and high probability had a score of 7. Severity score was based on assessment of a loss of component functionality and whether a public safety hazard would be created by a failure; the score was ranked from 1 to 7. If the risk assessment score was over 30, then climate change was expected to strongly impact the component and an engineering analysis by experts familiar with its design would be recommended. For components receiving a risk assessment score between 16 and 30 further considerations of climate change impacts would be advisable. For components with a score less than 16, no further consideration would be needed because climate change impacts are anticipated to be minor.

A problem with the risk assessment step was with participants anticipating extreme events. It was important to avoid getting deflected from the process by analysing data at this stage. Probability at the first stage was merely a rough scale not tied to data probability. In the case of the in-SHUCK-ch FSR, the valley has experienced three large frontal systems in the last 20 years, and extreme rains are predicted for the future; therefore, a probability of 6 was assigned. Severity of damage to most bridges at this extreme event level would be 6 (hazardous) while a few at the south end of the valley would be 7 (catastrophic).

Culvert failure severity was anticipated to be large (7) because a completely washed out culvert leaves a hole in the road prism, creating a safety hazard for road users (Figure 7), and requiring helicopters or a temporary bridge to restore road access.

The engineering analysis step has various components, including verifying and refining the climatic predictions and assessing load capacity vulnerability. Those familiar with the design of the infrastructure components review the design assumptions, material properties, etc. to assess the anticipated changes in performance given the climate changes predicted. If design changes are warranted to ensure safety or reliability, then these are recommended. The anticipated changes are often reviewed by maintenance contractors.

The analysis team determined that considering the scope and objectives of the case study and the information available it was not necessary to perform an engineering analysis of the infrastructure response to climate change on the in-SHUCK-ch FSR.

Outcome: highly vulnerable components

The following are those components for which the probability and severity indicated that climate change is anticipated to strongly impact the component. The recommended response is to refine the climatic predictions and anticipate changes in performance given the predicted climate changes. Thereafter, remediation of existing structures and design changes to future structures may be warranted. Partington et al. (2017) provides an extensive discussion of climate change adaptation measures for resource road infrastructure.

Highly -vulnerable to extreme temperature

Riparian habitat and debris flow routes. *Prolonged dry periods* further reduce low water flows and increase wildfire hazard. Aquatic organisms and habitat are threatened by low water levels, higher water temperatures, and riparian vegetation lost to wildfires. Prolonged hot dry periods are predicted to increase in frequency from 0.5 per year to 1 per year by 2041, to 2 per year by 2071. Prolonged dry periods followed by heavy rains increase the likelihood of heavy runoff and debris torrent initiation. Heavy runoff and debris torrents can scour or degrade stream channels and riparian habitat.

Major and minor culverts. *Daily temperature swings by more than 25° C* typically occur in the spring and have been occurring 1.5 times per year, on average. They are predicted to increase in frequency to 2 times, on average, per year by 2041. More frequent dramatic daily shifts in temperature are anticipated to promote the formation of ice build-up and obstructions in the barrels of both major and minor culverts.

Highly -vulnerable to extreme precipitation

Bridges, minor and major culverts, ditches, and cut slopes. Failures and damage to these five types of infrastructure on the in-SHUCK-ch FSR was linked to heavy rainfall. That is, the heavy rainfall led to high storm flows which caused increased erosion and, in the case of culverts, blockages and wash outs.

Extremely high rainfalls and sustained rainfall events (e.g., atmospheric rivers and pineapple express systems) are predicted to become more frequent and intense by 2041 although the annual precipitation along the FSR is not predicted to increase much. The frequency and intensity of antecedent rain followed by a significant rain event also is predicted to become more frequent by 2041 and intense in the north part of the FSR. These extreme rainfall events increase the likelihood of both landslides and debris torrents along the in-SHUCK-ch FSR, especially when over 100 mm rain falls (in-SHUCK-ch FSR PIEVC workshop comment from G. Mansell and B. Gladstone (local road maintainers)). These events will mobilize bedload and debris that could block, sweep away, or bury stream crossing structures and adjoining roadway.

Outcome: components for further consideration

The following types of infrastructure along the in-SHUCK-ch FSR were found to have a moderate risk and, therefore, required further consideration for the impacts of climate change. Typical adaptation measures for this level of risk might include additional monitoring and planning, and changes to maintenance practices.

Temperature-vulnerable components for further consideration

***Summer maintenance*.** Summertime periods of drought impact summer maintenance activities because they promote dusty conditions on the FSR that require a maintenance response (watering and (or) application of dust control chemicals). Prolonged dry periods of 30 days or more are predicted to grow increasingly frequent in the future (from 0.5 per year now to 1 per year by 2041, and to 2 per year by 2071). Periods with temperatures exceed 35°C for 10 or more days are predicted to become a common occurrence by 2041.

***Winter maintenance*.** Winter maintenance activities on the in-SHUCK-ch FSR, such as snow plowing, salting and sanding are impacted by snow falls but also by late winter temperature fluctuations. When temperature fluctuations of 25° C or more occur in the winter or early spring, they cause snow banks to slump and encroach on the road width, and the road surface to thaw to a shallow depth making it susceptible to traffic rutting and potholes. It is expected that by 2041, the in-SHUCK-ch will have less snowfall but an increased frequency of days experiencing a 25° C or more fluctuation in ambient temperature.

***Bridges, major and minor culverts, and ditches*.** Debris torrents can plug and damage stream crossing structures (culverts and bridges) and block roads and ditches. These powerful events have occurred periodically in the steep mountain stream channels incising the terrain surrounding Lillooet Lake and Lillooet River. Lake edge debris fans mark existing debris torrent paths (e.g., Strawberry Point (near KM 6), Lillooet Lake Lodge (near KM 12), and Lizzie Bay (near KM 15). Long periods of dry weather (e.g., less than 2.5 mm precipitation during a period of 30 days or more in which the daily high temperatures exceed 15° C) will cause soils to dry out and become hydrophobic. A significant rainfall following one of these prolonged dry spells may result in rapid, concentrated surface runoff which can be enough to trigger debris torrents. Prolonged hot dry periods are predicted to increase in frequency from 0.5 per year to 1 per year by 2041, to 2 per year by 2071.

***Cut slopes and unmanaged upslope hillslopes beyond the road prism*.** Water stress can cause plant die-off and drying out of cut slopes which can destabilize cut slopes and upslope features above the FSR. In the past, localized slope instability has led to increased raveling, erosion, and fire hazard. Prolonged periods of warm dry weather with minimal precipitation, and the incidence of extremely hot periods of weather (over 35°C for over 10 days) promote rapid soil drying, especially on south and west-facing slopes. Additionally, intense rainfall events following prolonged dry periods increase the potential for debris torrents. Prolonged dry periods of 30 days or more are predicted to be more frequent in the future; periods with temperatures exceed 35°C for 10 or more days are predicted to become a common occurrence by 2041.

***Cut slopes (rock and soil)*.** Sloughing and rock falls from cut slopes and rock faces are a constant source of concern along the FSR, especially during periods of wet weather and freeze-thaw periods. Warmer winters, combined with more rainfall, are predicted for the in-SHUCK-ch area. This will increase the frequency and severity of sloughing and rock falls from cut slopes and rock faces.

Major and minor culverts and ditches. Ice fall from rock faces, and ice buildup in culverts and ditches leads to water backing up and requires steam cleaning and clearing by maintenance crews. Warmer winters with more frequent rainfall are predicted for the in-SHUCK-ch area and this may increase icing issues.

***Road surfacing*.** Winter temperatures hovering near -1° C, and ice fogs, promote black ice development on road surfaces. Although not historically common on the in-SHUCK-ch FSR, it could become more of a concern in the future as winters warm, and become wetter.

***Debris torrent initiation*.** Following prolonged dry periods, dried out surface materials or burnt over areas may become hydrophobic. If the dry period is followed by a heavy rain storm, the surface runoff will be rapid and concentrated in stream channels and may trigger debris torrents. As previously noted, the frequency of hot dry periods is predicted to increase by 2041.

***Snow avalanche zones, administration, personnel and engineering*.** Variable temperatures, rain on snow, and shallow frost penetration result in weaker, unstable, snow packs, and increase the likelihood of avalanches. Future climate for the in-SHUCK-ch FSR corridor includes increased incidence of temperature fluctuations, more rain events in winter (although not more rain-on-snow events), and shallower frosts. The area has many avalanche chutes that will require additional monitoring and potentially more maintenance work to clear the road in the event of an avalanche. In the future, however, as snowpack levels decrease, rain-on-snow events and snow avalanches should become less of an issue.

Precipitation-vulnerable components for further consideration

Administration, personnel, engineering, and seasonal maintenance. The frequency of extreme and sustained rainfall events are predicted to increase on the in-SHUCK-ch FSR corridor due to climate change.

As a result, additional monitoring of infrastructure components on the road corridor will be required, along with an anticipated increase in summer and winter maintenance, to ensure road user safety.

Road surfacing. Extreme and sustained rainfall events promote road surface erosion and create potholes, ruts, pooling water, raveling, and fill slope slumps. In the future, the intensity and frequency of heavy rain events are predicted to increase for the in-SHUCK-ch area.

***Minor culverts, ditches, and cut slopes*.** Antecedent rainfall followed by an intense rain can impact road drainage infrastructure if nearby forest soils are already partially saturated. Antecedent plus an intense rainfall event can trigger slumps of cut slopes which in turn may block ditches and cross drain culverts. Ditches already carrying water may become overwhelmed resulting in backed up culverts or water pooling on roadways. The frequency of antecedent rainfall followed by an intense rain is predicted to increase dramatically by 2041 in the north part of the in-SHUCK-ch FSR, and to a lesser degree in the south.

***Embankments and fill slopes*.** Extreme and sustained rainfall events on embankment and fill slopes may cause severe erosion, slumping or trigger a debris torrent. Further, if these events occur following a period of prolonged dry weather, the soils may be resistant to water infiltration and the increased runoff may impact downslope values. Extremely high rainfalls and sustained rainfall events are predicted to become more frequent and intense for the in-SHUCK-ch area by 2041.

Retaining walls (all types). The prediction of increased frequency of sustained rainfall events in the in-SHUCK-ch FSR corridor warrants further consideration of the impacts to retaining walls.

***Upslope hillslopes beyond the road prism (all types)*.** Several upslope locations along the in-SHUCK-ch FSR corridor have active logging or are prone to landslides. Examples of this are Twin Creek 1 ad 2 where active logging is occurring upslope of the road corridor and Lizzy Creek where there is a history of landslides. These areas require further consideration to mitigate expected climate change issues caused by more frequent extremely hot weather, more frequent and intense rain events, and more frequent antecedent rain followed by an intense rain event.

***Debris torrent initiation*.** Saturated soils may be prone to debris torrents, especially as the frequency and intensity of extreme and sustained rainfall events increases. There is potential for the debris to impact infrastructure, streams, and other downslope values which requires further consideration.

Alluvial fan features**.** Increased frequency of extreme and sustained rainfall may worsen existing channel evulsions along Lillooet Lake, and at 11 km on the Fire Creek road and 73 km on the Dragon Fly road. Additionally, these intense rainfall events will cause further erosion and transportation of sediments, increasing the footprint of alluvial fans and potentially destabilizing them. Where there are existing residential developments or FSR infrastructure on an alluvial fan, careful consideration is warranted.

Riparian habitat, fish sensitive streams, river hydraulics, and flood plain migration**.** Increased annual precipitation to 1090 mm in the north and 1515 mm in the south may cause increased erosion and sedimentation into water courses and potentially alter water chemistry. Depending on the severity this could have an effect on riparian habitat and fish sensitive streams. Additionally, increased annual precipitation and frequency of extreme and sustained rainfall events may affect river hydraulics and cause flood plain migration at the north ends of Lillooet Lake and Harrison Lake, which could impact local habitat, and cause channel bank erosion and damage to road infrastructure.

5. Recommendations

Streamlining the PIEVC process

The PIEVC process workshop provided a formal, systematic, and comprehensive approach to assess the risk of climate-related impacts to an FSR's infrastructure. The process effectively compiled local knowledge and technical expertise about extreme weather impacts and extended these into the future using state-of-the-art climatology prediction methods. Due to the complex and comprehensive nature of this work, the workshop and subsequent completion of the assessment by FPInnovations took considerable time. It is recommended that the PIEVC process be streamlined so that the workshop process focuses on a pre-sorted set of resource road infrastructure and key climatic parameters. Also, it is recommended that this assessment be used as a baseline from which general learnings about climate change vulnerability can be derived through comparing and contrasting results with those from other resource road assessments.

Climate adaptation responses for the in-SHUCK-ch FSR

The following section presents recommended actions arising from the PIEVC workshop and subsequent analysis of the in-SHUCK-ch FSR. For reasons of brevity, the discussion is preliminary and general in nature, and focused only on highly or moderately vulnerable infrastructure identified by the PIEVC analysis.

Capacity building. FSR managers and maintenance supervisors, supervisors of industrial operations that use the FSR, and representatives of the communities accessed by the FSR should review this report and become familiar with the climate change predictions for the in-SHUCK-ch FSR corridor and how these are likely to impact the performance of vulnerable infrastructure components.

While this analysis was intended to identify the relative vulnerability of resource road infrastructure to climate change, specific recommendations about upgrades to individual structures, or design changes, are outside of its scope.

The next steps to fashioning a response to the contents of this report are to summarize knowledge about the most vulnerable types of infrastructure along the in-SHUCK-ch FSR corridor, prioritize which structures are at highest risk based on historic performance, and begin to fashion proactive and reactive responses to extreme weather events and general climate changes. Readers are referred to (Partington et al. 2017) for an extensive discussion of climate change adaptation measures for resource road infrastructure.

Road managers and maintenance staff should begin (or continue) to gather details about weather events that coincide with peak stream flows and infrastructure failures.

Increasing the understanding of how local weather impacts steam flows and infrastructure performance will empower managers, designers, and maintenance supervisors to reduce the vulnerability of road infrastructure and control risk associated with local climate changes. Additionally, road managers and maintenance staff should document the details surrounding historical infrastructure failures on the in-SHUCK-ch FSR so that this knowledge is retained after experienced staff retires from the workforce.

Emergency readiness planning. The in-SHUCK-ch FSR and the Lillooet West FSR provide access to a number of First Nations communities at the south end of the in-SHUCK-ch area. These roads are separated by a large, fast flowing river and there are only two bridges across the river. While the First Nations communities along the Lillooet River are somewhat remote and vulnerable to road and bridge access failures they do have a parallel road network and two bridge connections. In the event of failure there would still be access between all of the communities. Even greater vulnerability exists where access is provided by only a single road. If there were road and (or) bridge failures at the north end of the in-SHUCK-ch FSR (KM 0 to KM 28), the whole road network and all of the communities south of the failure would be isolated.

Contingency plans to provide all communities with medical support, supplies and communications, and emergency access in the case of bad weather and road and (or) bridge failures should be reviewed in light of the predicted climate changes and infrastructure vulnerabilities.

Debris fan planning. A number of debris fans at the lake edge have residential housing developments; however, given the nature of these fans and the surrounding steep terrain they are areas of high geological risk. The PIEVC process predicts climate changes that will promote high stream flows, debris torrents and landslides, and channel evulsion at these sites. Plans for each development should be reviewed in light of the increasing future risks and steps developed to safe guard lives and property, and minimize access disruption in the event of a debris torrent occurring. Consideration should be given to developing robust emergency plans for each development, identifying the highest risk areas on each fan, and creating more resilient road infrastructure for the portions of FSR on these fans.

Road drainage review and inspection. Minor culverts are not usually designed for specific watersheds but, rather, are sized according to local experience, cost, and (or) a provincial standard. Additionally, owing to the large number of small culverts in use these structures commonly are not well maintained. It is recommended that road maintainers review the number, location, and diameter of existing water management structures along the in-SHUCK-ch FSR, and its tributary roads. The performance of these structures should be observed after it has been raining for several days. Based on the inventory and inspection results, focus efforts to address culvert deficiencies.

Deepen ditches, re-establish ditch blocks, armour cross drain outfalls, and install additional cross drains, as required, to handle the increase in precipitation predicted to 2041. Activities to improve drainage resiliency should start at the north end of the FSR where traffic levels are higher and road network function is most vulnerable to a washout.

Managing the vulnerability of stream crossing structures. Extreme rainfall events may generate high stream flows containing large amounts of mobilized bedload and woody debris that endanger bridges and other stream crossings. The climate analysis for the in-SHUCK-ch area predicts increased frequency and intensity of extreme rainfall events.

It is recommended to inspect stream crossing structures after all heavy storms, and before the winter rainy season starts, to identify and document erosion concerns, scouring, evidence of overtopping, and accumulations of debris and bedload in and around the structures. It is also advisable to inspect the channel reach upstream of the crossing to identify and help plan for any large boulders and woody debris likely to reach the crossing in the next storm. When erosion, overtopping, or deposition concerns arise make note of the weather event(s) associated with them. Repair or upgrade rip-rap armouring to protect vulnerable parts of the crossing structure and adjacent stream channel. Remove bedload and debris accumulations that substantially reduce hydraulic capacity of the crossing structure.

Increased road maintenance effort. Summer and winter maintenance activities and budgets should be reviewed and adjusted, as needed, to better manage the risks associated with climate change. There will be increased administration and engineering effort needed to monitor, inspect for damage, and protect public safety.

“*This document should be used as the basis to change the present road maintenance best management practices, policies, and perhaps legislation to ensure that the road systems are being protected. At present minimal road maintenance is being done by the licensees and government. Most of the maintenance is reactionary at best. There should be a recommendation to use this document to take this to the next steps to inform government of the risks and costs of not doing a better job of maintenance of the road system. The roads in the Chilliwack and STS were not designed 50 years ago for the current use by the public*.”[1]

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[1] May 2018 recommendation from Gene MacInnes, R.P.F., MacInnes and Associates, construction supervisor for numerous projects on the IN-SHUCK-ch FSR, and PIEVC analysis participant.

6. References

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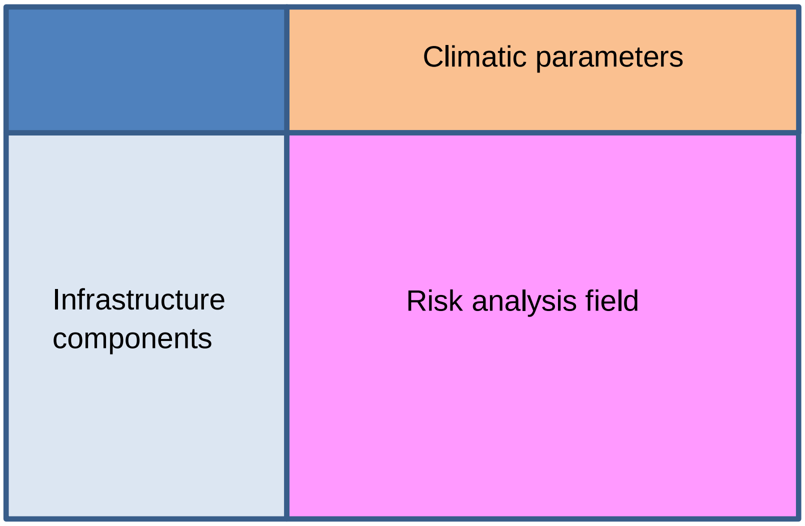
7. Appendix A. PIEVC Process Analysis of in-SHUCK-ch FSR Corridor Infrastructure and Terrain

Spreadsheet format

The risk assessment spreadsheet is structured as a matrix in which the rows are infrastructure components and columns are the climatic parameters. Each interaction is initially screened as to whether the infrastructure component ***sees*** the climatic parameter (Y/N). For instance, a buried structure may not be affected by an extreme high temperature; in this case, this interaction should not be assessed. The purpose of this analysis is to streamline the assessment process and to avoid assigning probability and severity scores to an interaction that will not affect that infrastructure. The preliminary screening question, and the probability, severity and risk scores appear in the risk analysis field.



Schematic of spreadsheet used in the risk assessment

		Temperature																																		
		1					12					3					4					5					6a					6				
	Road Infrastructure Components If R < 16, the influence of climate change is anticipated to be minor on the element in question and no further consideration is needed. If 16 < R < 30, further consideration might be needed. If R > 30, climate change is anticipated to strongly impact the element and detailed engineering analysis by experts familiar with its design is recommended.	High Temperature					Prolonged Dry Period					Average Temperature					Daily temperature variation					Freeze/Thaw					Rock Face Ice Build-up					Frost and Frost Penetration				
		Day(s) with max. temp. exceeding 35°C				10 days on average to the 2040s **Relevence to bridge design:** max design temp from 34°C to 49°C depending on structure: concrete or steel	>30 consecutive days with max > 15 C & < 2.5mm ppt				implications for dryness leading to: dust abatement, cut slope ravelling, rockfall & wildfire effects (increased runoff, debris flow potential, fire hazard) check with Lyle Gwa	Average Maximum Temperature Over 7 Days				Current 7-day avg 30°C (34°C 90th percentile), 35oC by 2040's (36°C for 90th percentile) measure of short term high temp relevant to fire indices, landslide trigger	Daily temperature variation of more than 25°C				up to 2040's 1 day ±1day every 1.5 years **Relevance to Bridges** Range for bridge could be either 104°C or 79°C depending on structure type	Number of days where max. temp. >0°C and min. temp.<0°C Not consecutive days. Concern is total number of events.				90 ± 9 days This parameter also affects how much frost growth will occur in subsoils, below foundations etc. Rock fall related to freeze/thaw (km 1 on the In-SHUCK-ch) Fog generation	7 days temperature max < -5°C				1.5 times per year up to 2040's ice build-up on rock faces resulting in rock and ice fall onto road prism ditch and culvert and crossdrain ice buildup	Degree days <0				**Road:** Mainly affects how thick the road gravels need to be to deal with frost heaving in the subsoil. Frost >2ft depth (Frost probe data available)
		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
	Structures that cross streams:																																			
2	§ Bridges	Y	7	5	35		Y	6	3	18		N	7				Y	7	0	0		Y	7	3	21		N	7				Y	7	1	7	
3	§ Major (>1800mm dia; >6m3s)	N	7		0		Y	6	3	18		N	7				Y	7	7	49		N	7		0		Y	7	3	21		Y	7	1	7	
4	§ Other culverts (<2000mm)	N	7		0		Y	6	3	18		N	7				Y	7	7	49		N	7		0		Y	7	3	21		Y	7	1	7	
5	Culvert cross drains	N	7		0		N	6				N	7				N	7				N	7		0		Y	7	3	21		Y	7	1	7	
7	Ditches	N	7		0		N	6				N	7				N	7				N	7		0		Y	7	4	28		N	7			
1	Road surfacing	N	7		0		N	6				N	7				N	7				Y	7	3	21		Y	7	2	14		Y	7	1	7	
10	Embankment/Fill Slopes	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
11	Cut Slopes - Other Material (OM)	Y	7	2	14		Y	6	4	24		N	7				N	7				N	7	3	21		N	7				Y	7			
11	Cut Slopes - rock	N	7		0		Y	6	0	0		N	7				N	7				Y	7	3	21		Y	7	2	14		Y	7	2	14	
10	Upslope hillslopes beyond road prism - managed	N	7		0		Y	6	3	18		N	7				N	7				N	7		0		N	7				N	7			
10	Upslope hillslopes beyond road prism - unmanaged	N	7		0		Y	6	2	12		N	7				N	7				Y	7	3	21		N	7				N	7			
10	Dnslope hillslopes beyond road prism - managed	N					Y	6	2	12		N	7				N	7				N	7		0		N	7				N	7			
10	Dnslope hillslopes beyond road prism - unmanaged	N	7		0		Y	6	0	0		N	7				N	7				N	7		0		N	7				N	7			
11	River training works	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
12	Retaining walls (lock block, rock stack, log, etc)	N	7		0		Y	6	0	0		N	7				N	7				N	7		0		N	7				Y	7	1	7	
13	§ MSE/GRS walls/fills	N	7		0		Y	6	0	0		N	7				N	7				N	7		0		N	7				Y	7			
6	Signage	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
	Third party utilities:																																			
15	§ Hydro poles/towers	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
16	§ Hydro lines	Y	7	7	49		Y	6	0	0		N	7				N	7				N	7		0		N	7				N	7			
17	§ Communication/utility towers	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
17	§ water lines	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
19	Archeological sites (Grave sites; FN sites)	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
	Environmental Features																																			
20	River hydraulics	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
	Flood plain migration	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
23	Lake level flooding	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
	Alluvial fan features	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
21	Landslide initiation	N	7		0		Y	6	2	12		Y	7	7	49		N	7				N	7		0		N	7				N	7			
21	Debris flow initiation	N	7		0		Y	6	5	30		N	7				N	7				N	7		0		N	7				N	7			
22	Snow avalanche zones	N	7		0		N	6				N	7				N	7				N	7		0		N	7				Y	7	4	28	
24	Riparian habitat/Fish sensitive streams	N	7	2	14		Y	6	7	42		N	7				N	7				N	7		0		N	7				N	7			
	Miscellaneous																																			
25	Administration/personnel & engineering	Y	7	2	14		Y	6	2	12		N	7				N	7				N	7		0		Y	7	2	14		Y	7	3	21	
27	Winter maintenance	N	7		0		N	6				N	7				Y	7	3	21		Y	7	2	14		Y	7	1	7		Y	7	3	21	
28	Summer maintenance	Y	7	3	21		Y	6	3	18		N	7				N	7				N	7		0		N	7				N	7			
30	Gravel/rock pits/spoil sites	N	7		0		N	6				N	7				N	7				N	7		0		N	7				N	7			
		5					17					1					4					5					8					12				
	Total Interactions Considered	334																																		

		Precipitation as Rain																			
		7					8					9					10				
		Total Annual Precipitation					Extreme High Rainfall in 24 hour period					Sustained Rainfall					Antecedent rain followed by significant rain event				
	Road Infrastructure Components If R < 16, the influence of climate change is anticipated to be minor on the element in question and no further consideration is needed. If 16 < R < 30, further consideration might be needed. If R > 30, climate change is anticipated to strongly impact the element and detailed engineering analysis by experts familiar with its design is recommended.	1090 mm (North) and 1515 mm (South)				Relevance = water management Based on observed 30 year average total annual rainfall.	>20-year-return period. 60 mm & 80 mm rain in 24 hour period in north & south				predicted to increase frequency to 10-year-period. Relevance = culvert and bridge design, road surface, safety Adjust to consider dry/wet zone as appropriate	≥ 3 consecutive days with 100 & 150 mm rain/day in north & south (20 year return period) Not on snow				Predicted to increase frequency to 8 yr rtn period in 2040 to 2070. Relevance = culvert and bridge design, road surface, safety	Antecedent: 14 consecutive days cumulative amount >150 mm rain followed by 24 hr rainfall exceeding 50 mm				Matthias reference 2 wks impacts to cut/fill slopes, landslides refer Bill Floyd
		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
	Structures that cross streams:																				
2	§ Bridges	N	6				Y	6	5	30		Y	6	5	30		Y	3	5	15	
3	§ Major (>1800mm dia; >6m3s)	N	6				Y	6	7	42		Y	6	7	42		Y	3	7	21	
4	§ Other culverts (<2000mm)	N	6				Y	6	7	42		Y	6	7	42		Y	3	7	21	
5	Culvert cross drains	Y	6	2	12		Y	6	7	42		Y	6	7	42		Y	3	7	21	
7	Ditches	Y	6	3	18		Y	6	5	30		Y	6	6	36		Y	3	5	15	
1	Road surfacing	Y	6	2	12		Y	6	3	18		Y	6	4	24		Y	3	3	9	
10	Embankment/Fill Slopes	Y	6	2	12		Y	6	3	18		Y	6	4	24		Y	3	3	9	
11	Cut Slopes - Other Material (OM)	N	6				Y	6	5	30		Y	6	5	30		Y	3	4	12	
11	Cut Slopes - rock	N	6				N	6	2	12		N					Y	3	1	3	
10	Upslope hillslopes beyond road prism - managed	N	6				Y	6	3	18		y	6	3	18		Y	3	2	6	
10	Upslope hillslopes beyond road prism - unmanaged	N	6				Y	6	3	18		y	6	3	18		Y	3	2	6	
10	Dnslope hillslopes beyond road prism - managed	N	6				N	6	1	6		N					Y	3	1	3	
10	Dnslope hillslopes beyond road prism - unmanaged	N	6				N	6	1	6		N					Y	3	1	3	
11	River training works	N	6				N	6	1	6		N					Y	3	2	6	
12	Retaining walls (lock block, rock stack, log, etc)	N	6				N	6	2	12		Y	6	3	18		Y	3	3	9	
13	§ MSE/GRS walls/fills	N	6				Y	6	1	6		N					Y	3	1	3	
6	Signage	N	6				N	6	1	6		N					N				
	Third party utilities:																				
15	§ Hydro poles/towers	N	6				N	6	1	6		N					N				
16	§ Hydro lines	N	6				N	6	1	6		N					N				
17	§ Communication/utility towers	N	6				N	6	1	6		N					N				
17	§ water lines	N	6				N	6	1	6		N					N				
19	Archeological sites (Grave sites; FN sites)	N	6				N	6	1	6		N					N				
	Environmental Features																				
20	River hydraulics	Y	6	2	12		N	6	2	12		Y	6	3	18		Y	3	2	6	
	Flood plain migration	Y	6	2	12		N	6	1	6		Y	6	3	18		Y	3	2	6	
23	Lake level flooding	Y	6	2	12		N	6	1	6		N					Y	3	1	3	
	Alluvial fan features	Y	6	2	12		Y	6	3	18		Y	6	3	18		Y	3	2	6	
21	Landslide initiation	N					Y	6	5	30		Y	6	6	36		Y	3	5	15	
21	Debris flow initiation	Y	6	2	12		Y	6	4	24		Y	6	5	30		Y	3	4	12	
22	Snow avalanche zones	Y	6	2	12		N	6	1	6		N					Y	3	1	3	
24	Riparian habitat/Fish sensitive streams	**Y**	**6**	**3**	**18**		N	6	1	6		N					N				
	Miscellaneous																				
25	Administration/personnel & engineering	**Y**	**6**	**3**	**18**		Y	6	5	30		Y	6	5	30		Y	3	3	9	
27	Winter maintenance	**Y**	**6**	**2**	**12**		Y	6	4	24		Y	6	4	24		Y	3	4	12	
28	Summer maintenance	N	6				Y	6	4	24		Y	6	4	24		Y	3	4	12	
30	Gravel/rock pits/spoil sites	N	6				N	6	1	6		N					Y	3	1	3	
		13					17					19					27				

		Precipitation as Rain														
		11					13					14				
		Low Rainfall					Snow Frequency					Snow Accumulation				
	Road Infrastructure Components	≥ 10 consecutive days with precipitation < 0.2 mm				no info from models (relevance for fire hazard)	Snow frequency: days with snowfall > 10cm (Tavg < 1° C) Currrently 5 days/ yr				Predicted to be 3 days/ yr Relevance = when need to plough road	Snow accumulation: 5 or more consecutive days with a snow depth >60cm 87 cm per year now				measure of how much snow accumulates on road edges due to snowfall and from snow plowing. Snow on hills above road. Predicted to drop to 40 cm per year 2011 to 2040
		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
	Structures that cross streams:															
2	§ Bridges	N					N	6		0		N	5			
3	§ Major (>1800mm dia; >6m3s)	N					N	6		0		N	5		0	
4	§ Other culverts (<2000mm)	N					N	6		0		N	5		0	
5	Culvert cross drains	N					N	6		0		Y	5	2	10	
7	Ditches	N					N	6		0		Y	5	4	20	
1	Road surfacing	N					Y	6	3	18		Y	5	3	15	
10	Embankment/Fill Slopes	Y	6	2	12		N	6		0		N	5			
11	Cut Slopes - Other Material (OM)	Y	6	2	12		N	6		0		N	5			
11	Cut Slopes - rock	N					N	6		0		N	5			
10	Upslope hillslopes beyond road prism - managed	Y	6	3	18		N	6		0		N	5			
10	Upslope hillslopes beyond road prism - unmanaged	Y	6	3	18		N	6		0		N	5			
10	Dnslope hillslopes beyond road prism - managed	Y	6	3	18		Y	6	3	18		N	5			
10	Dnslope hillslopes beyond road prism - unmanaged	Y	6	3	18		N	6		0		N	5			
11	River training works	N					N	6		0		N	5			
12	Retaining walls (lock block, rock stack, log, etc)	N					N	6		0		N	5			
13	§ MSE/GRS walls/fills	N					N	6		0		N	5			
6	Signage	N					Y	6	2	12		Y	5	3	15	
	Third party utilities:															
15	§ Hydro poles/towers	N					N	6		0		Y	5	2	10	
16	§ Hydro lines	N					N	6		0		N	5			
17	§ Communication/utility towers	N					N	6		0		N	5			
17	§ water lines	N					N	6		0		Y	5	3	15	
19	Archeological sites (Grave sites; FN sites)	N					N	6		0		N	5			
	Environmental Features															
20	River hydraulics	N					N	6		0		N	5		0	
	Flood plain migration	N					N	6		0		N	5		0	
23	Lake level flooding	N					N	6		0		N	5		0	
	Alluvial fan features	N					N	6		0		N	5		0	
21	Landslide initiation	N					N	6		0		N	5		0	
21	Debris flow initiation	N					N	6		0		N	5		0	
22	Snow avalanche zones	N					N	6		0		Y	5	4	20	
24	Riparian habitat/Fish sensitive streams	Y	6	3	18		N	6		0		N	5		0	
	Miscellaneous															
25	Administration/personnel & engineering	N					Y	6	2	12		Y	5	3	15	
27	Winter maintenance	N					Y	5	4	20		Y	5	5	25	
28	Summer maintenance	Y	6	2	12		N	5		0		N	5		0	
30	Gravel/rock pits/spoil sites	N					N	5		0		N	5		0	
		8					5					9				

		Combined Events																																	
		15					16					17									18					19					20				
		Snow Storm/ Blizzard					Rain / Snow /Wind					Rain on Snow									Hail / Sleet					Rain on Frozen Ground					Freezing Rain				
	Road Infrastructure Components If R < 16, the influence of climate change is anticipated to be minor on the element in question and no further consideration is needed. If 16 < R < 30, further consideration might be needed. If R > 30, climate change is anticipated to strongly impact the element and detailed engineering analysis by experts familiar with its design is recommended.	8 or more days with blowing snow				no info from models	Rain on Snow Including Temperature and Wind Speed				ask Bill Floyd	Rain (50mm /24 hours) on >60 cm of "ripe"saturated snow pack; freezing > ridge tops								Relevance = excessive runoff	Days with Precipitation Falling as Ice Particles				no info from models	Precip > 25 mm/day Surface Temperature <0° C No snowfall				rain on frozen ground resulting in surface icing - traction and runoff issues	number of days with rain that falls as liquid and freezes on contact				Road surface icing - traction issue; visibility; iced tree debris & power line icing
		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
	Structures that cross streams:																2050																		
2	§ Bridges	Y	3	2	6		Y	3	6	18		Y	3	6	18	Y	2	6	12		Y	3	3	9		Y	2	6	12		Y	2	6	12	
3	§ Major (>1800mm dia; >6m3s)	N	3				N					Y	3	6	18	N	2	6	12		N					N					N				
4	§ Other culverts (<2000mm)	N	3				N					Y	3	7	21	N	2	7	14		N					N					Y	2	5	10	
5	Culvert cross drains	N	3				N					Y	3	7	21	N	2	7	14		N					Y	2	5	10		Y	2	5	10	
7	Ditches	Y	3	3	9		Y	3	5	15		Y	3	6	18	Y	2	6	12		N					Y	2	5	10		Y	2	5	10	
1	Road surfacing	Y	3	3	9		Y	3	5	15		Y	3	5	15	Y	2	5	10		Y	3	3	9		Y	2	6	12		Y	2	6	12	
10	Embankment/Fill Slopes	N	3				Y	3	5	15		Y	3	5	15	Y	2	5	10		N					N					Y				
11	Cut Slopes - Other Material (OM)	N	3				Y	3	5	15		Y	3	5	15	Y	2	5	10		N					N					Y				
11	Cut Slopes - rock	N	3				Y	3	3	9		Y	3	3	9	Y	2	3	6		N					N					Y				
10	Upslope hillslopes beyond road prism - managed	N	3				Y	3	4	12		Y	3	4	12	Y	2	4	8		N					N					Y				
10	Upslope hillslopes beyond road prism - unmanaged	N	3				Y	3	4	12		Y	3	3	9	Y	2	3	6		N					N					Y				
10	Dnslope hillslopes beyond road prism - managed	N	3				Y	3	3	9		Y	3	3	9	Y	2	3	6		N					N					Y				
10	Dnslope hillslopes beyond road prism - unmanaged	N	3				Y	3	4	12		Y	3	3	9	Y	2	3	6		N					N					Y				
11	River training works	N	3				N					Y	3	3	9	N	2	3	6		N					N					N				
12	Retaining walls (lock block, rock stack, log, etc)	N	3				Y	3	3	9		Y	3	3	9	Y	2	3	6		N					N					Y				
13	§ MSE/GRS walls/fills	N	3				Y	3	1	3		Y	3	1	3	Y	2	1	2		N					N					Y				
6	Signage	Y	3	3	9		Y	3	1	3		Y	3	1	3	Y	2	1	2		N					N					Y	2	5	10	
	Third party utilities:																																		
15	§ Hydro poles/towers	Y	3	2	6		N					N				N					N					N					Y	2	6	12	
16	§ Hydro lines	Y	3				N					N				N					N					N					Y	2	6	12	
17	§ Communication/utility towers	Y	3				N					N				N					N					N					Y	2	6	12	
17	§ water lines	Y	3	3	9		N					N				N					N					N					Y				
19	Archeological sites (Grave sites; FN sites)	N	3				N					N				N					N					N					N				
	Environmental Features																																		
20	River hydraulics	N	3				N					N				N					N					N					N				
	Flood plain migration		3				Y	3	4	12		N	0	4	0	Y	0	4	0		N					N									
23	Lake level flooding	N	3				Y	3	3	9		N	0	3	0	Y	0	3	0		N					N					Y				
	Alluvial fan features		3				Y	3	5	15		N	0	5	0	Y	0	5	0		N					N									
21	Landslide initiation	N	3				Y	3	6	18		N	0	6	0	Y	0	6	0		N					Y	2	5	10		Y	2	5	10	
21	Debris flow initiation	N	3				Y	3	5	15		N	0	5	0	Y	0	5	0		N					Y	2	5	10		Y	2	5	10	
22	Snow avalanche zones	Y	3	2	6		Y	3	3	9		N	0	3	0	Y	0	3	0		N					Y	2	5	10		Y	2	5	10	
24	Riparian habitat/Fish sensitive streams	N	3				Y	3	1	3		N	0	1	0	N	0	1	0		N					N					N				
	Miscellaneous																																		
25	Administration/personnel & engineering	Y	3	2	6		Y	3	5	15		N	0	5	0	Y	0	5	0		N					Y	2	4	8		Y	2	6	12	
27	Winter maintenance	Y	3	4	12		Y	3	6	18		N	0	6	0	Y	0	6	0		N					Y	2	4	8		Y	2	6	12	
28	Summer maintenance	N	3		0		N					N	0	1	0	N	0	1	0		N					N					N				
30	Gravel/rock pits/spoil sites	N	3		0		N					N	0	1	0	N	0	1	0		N					N					Y				
		11					**22**					**17**				**21**					**2**					**9**					**26**				

	Road Infrastructure Components If R < 16, the influence of climate change is anticipated to be minor on the element in question and no further consideration is needed. If 16 < R < 30, further consideration might be needed. If R > 30, climate change is anticipated to strongly impact the element and detailed engineering analysis by experts familiar with its design is recommended.	Infrastructure Specific Events														
		21					22					23				
		Visibility (Fog)					High Wind Combined with Rain					Rapid Snow Melt (not with rain)				
		≥ 15 hours per year with visibility < 1,000 m				Fog from the lake	number of days with max winds ≥ 63 km/hr and 50 mm rain/24 hrs				no info from models	snow melt > 30 mm/day				driver for lake levels during melt period
		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
	Structures that cross streams:															
2	§ Bridges	Y	6	4	24		N					Y	6	3	18	
3	§ Major (>1800mm dia; >6m3s)	N					Y	3	5	15		Y	6	3	18	
4	§ Other culverts (<2000mm)	N					Y	3	5	15		Y	6	4	24	
5	Culvert cross drains	N					Y	3	5	15		Y	6	4	24	
7	Ditches	N					Y	3	6	18		Y	6	3	18	
1	Road surfacing	N					Y	3	5	15		Y	6	2	12	
10	Embankment/Fill Slopes	N					N			0		Y	6	2	12	
11	Cut Slopes - Other Material (OM)	N					Y	3	5	15		Y	6	4	24	
11	Cut Slopes - rock	N					Y	3	5	15		Y	6	3	18	
10	Upslope hillslopes beyond road prism - managed	N					Y	3	6	18		Y	6	3	18	
10	Upslope hillslopes beyond road prism - unmanaged	N					Y	3	6	18		Y	6	3	18	
10	Dnslope hillslopes beyond road prism - managed	N					Y	3	5	15		Y	6	2	12	
10	Dnslope hillslopes beyond road prism - unmanaged	N					Y	3	5	15		Y	6	2	12	
11	River training works	N					N			0		Y	6	4	24	
12	Retaining walls (lock block, rock stack, log, etc)	N					N			0		Y	6	3	18	
13	§ MSE/GRS walls/fills	N					N			0		Y	6	3	18	
6	Signage	Y	6	3	18		Y	3	4	12		N				
	Third party utilities:															
15	§ Hydro poles/towers	N					N					N				
16	§ Hydro lines	N					Y	3	5	15		N				
17	§ Communication/utility towers	N					Y	3	5	15		N				
17	§ water lines	N					N					N				
19	Archeological sites (Grave sites; FN sites)	N					N					N				
	Environmental Features															
20	River hydraulics	N					N					Y	6	4	24	
	Flood plain migration											Y	6	4	24	
23	Lake level flooding	N					N					N				
	Alluvial fan features											Y	6	4	24	
21	Landslide initiation	N					N					Y	6	4	24	
21	Debris flow initiation	N					N					Y	6	4	24	
22	Snow avalanche zones	N					Y	3	4	12		Y	6	4	24	
24	Riparian habitat/Fish sensitive streams	N					Y	3	5	15		N				
	Miscellaneous															
25	Administration/personnel & engineering	N					Y	3	6	18		Y	6	4	24	
27	Winter maintenance	N					Y	3	6	18		Y	6	4	24	
28	Summer maintenance	N					Y	3	6	18		N				
30	Gravel/rock pits/spoil sites	N					N					N				
		2					19					24				

	Road Infrastructure Components	Infrastructure Specific Events														
		24					25					26				
		Snow Driven Peak Flow Events					Ice / Ice Jams					Ground Freezing				
											observations - ice in the lake but no ice problems	Number of Days Below -5° C				
		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
	Structures that cross streams:															
2	§ Bridges	Y	3	3	9		N					N				
3	§ Major (>1800mm dia; >6m3s)	Y	3	3	9		N					N				
4	§ Other culverts (<2000mm)	Y	3	4	12		N					N				
5	Culvert cross drains	Y	3	4	12		N					N				
7	Ditches	Y	3	4	12		N					N				
1	Road surfacing	N					Y	3	5	15		Y	3	3	9	
10	Embankment/Fill Slopes	Y	3	3	9		N					N				
11	Cut Slopes - Other Material (OM)	Y	3	3	9		N					N				
11	Cut Slopes - rock	Y	3	2	6		N					N				
10	Upslope hillslopes beyond road prism - managed	Y	3	3	9		N					N				
10	Upslope hillslopes beyond road prism - unmanaged	Y	3	3	9		N					N				
10	Dnslope hillslopes beyond road prism - managed	Y	3	3	9		N					N				
10	Dnslope hillslopes beyond road prism - unmanaged	N					N					N				
11	River training works	Y	3	3	9		Y	3	5	15		N				
12	Retaining walls (lock block, rock stack, log, etc)	Y	3	3	9		N					N				
13	§ MSE/GRS walls/fills	Y	3	3	9		N					N				
6	Signage	N					N					N				
	Third party utilities:															
15	§ Hydro poles/towers	N					N					N				
16	§ Hydro lines	N					N					N				
17	§ Communication/utility towers	N					N					N				
17	§ water lines	N					N					N				
19	Archeological sites (Grave sites; FN sites)	N					N					N				
	Environmental Features															
20	River hydraulics	Y	3	3	9		Y	3	5	15		N				
	Flood plain migration	Y	3	3	9		N									
23	Lake level flooding	Y	3	3	9		Y	0	5	0		N				
	Alluvial fan features	N					N									
21	Landslide initiation	Y	3	3	9		N					N				
21	Debris flow initiation	Y	3	3	9		N					N				
22	Snow avalanche zones	Y	3	3	9		N					N				
24	Riparian habitat/Fish sensitive streams	N					N					N				
	Miscellaneous															
25	Administration/personnel & engineering	N					Y	3	5	15		Y	3	4	12	
27	Winter maintenance	Y	3	3	9		Y	3	5	15		Y	3	4	12	
28	Summer maintenance	N					N					N				
30	Gravel/rock pits/spoil sites	N					N					Y	3	5	15	
		21					6					4				

8. Appendix B. Project team

The assessment and advisory teams consisted of representatives from various industries and government departments to ensure that there was diversity in the knowledge, expertise, and experience as related to the PIEVC process and the in-SHUCK-ch FSR. The members of the assessment team are listed in the following table:

Assessment team members

Team Member	Position	Organization
Gino Fournier	Engineering Group Leader	FLNRORD
Brian Chow	Chief Engineer	FLNRORD
Malcolm Schulz	District Engineering Officer	FLNRORD
Dave Spittlehouse	Climatologist	FLNRORD
Dirk Nyland	Chief Engineer	MOTI
Jim Barnes	Manager, Corporate Initiatives	MOTI
Allan Bradley	Associate Research Leader	FPInnovations

Dirk Nyland and Jim Barnes of MOTI facilitated the implementation of the PIEVC process and led the assessment team and advisory group through the vulnerability assessment during the workshop.

The advisory team participated in the vulnerability assessment workshop and provided local expertise and knowledge of the road and its surroundings, the road's usage, and past and future desired performance levels. The members of the advisory team are listed in the following table:

Advisory team members

Team Member	Position	Organization
Pierre Friele	Consulting Geoscientist	Cordilleran Geoscience Ltd.
Gord Menzel	Operations Manager	Lizzie Bay Logging Ltd.
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