info@fpinnovations.ca
www.fpinnovations.ca

ANALYSIS OF A BRITISH COLUMBIA RESOURCE ROAD'S VULNERABILITY TO CLIMATE CHANGE:

WILLOW FOREST SERVICE ROAD PIEVC CASE STUDY

Mark Partington, R.P.F., M.Sc., Senior Researcher
Allan Bradley, R.P.F., P.Eng., Lead Researcher

November 2019

Non-restricted distribution

FPInnovations

This report presents a case study of the vulnerability to climate change of infrastructure on the Willow 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.

301012843: ADAPTING FOREST OPERATIONS TO CLIMATE CHANGE

TECHNICAL REPORT—18

ACKNOWLEDGEMENTS
This project was financially supported by Natural Resources Canada under the NRCan/ CFS-FPInnovations contribution agreement.

The authors wish to acknowledge the technical assistance provided by Brian Chow and David Spittlehouse of B.C. Forests, Lands, Natural Resource Operations and Rural Development.

AUTHOR CONTACT INFORMATION
Mark Partington, R.P.F., M.Sc.
Senior Researcher
Roads and Infrastructure
(514) 782-4525
mark.partington@fpinnovations.ca

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The management of resource roads is an important consideration for governments and industry across Canada. Resource roads support industrial operations, recreational activities, and access for communities. The need to mitigate the impacts of climate change to resource roads and the requirement to identify and mainstream adaptation practices is of increasing importance. This need is of increased relevance in British Columbia where the varied and complex geography increases the impact of changes in climate patterns. In recognition of this, the B.C. government has developed a Climate Change Strategy mandate within the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNR).

In support of both the broad climate change adaptation needs for resource roads in Canada, and to meet the specific objectives in B.C., FPInnovations partnered with FLNR to conduct a case study using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol to assess the vulnerability of a resource road to climate change. This case study analyzed the 92 km-long gravel-surfaced portion of the Willow Forest Service Road starting approximately 3 km south of Prince George city limits and 500 m from the Carrier Lumber mill.

The climate modelling and forecasting determined that, in general for the area of the Willow FSR, annual precipitation is forecasted to increase with less precipitation in the summer and greater amounts of precipitation in the winter, spring, and fall. Warmer temperatures will occur in both summer and winter, with a shorter winter snow season forecasted.

At a one day-long workshop, the assessment team scored the severity of extreme weather impacts on infrastructure and reviewed probability scores for the climate parameters for each of the 121 interactions between the infrastructure and climate. Following the workshop, the analysis was completed by FPInnovations in consultation with the assessment team. This report provides a series of recommendations derived from the results of the analysis. These recommendations include capacity building of road resiliency actions by road managers and stakeholders, expanding road maintenance interventions, further development of infrastructure inspection and inventory procedures, and an evaluation of technologies and practices to mitigate thaw-weakening of road surfaces and subgrades during mid-winter thaws and spring.

This case study provides a benchmark for future iterations of the process and provides meaningful analysis of the risks and opportunities faced by the Willow FSR corridor.

INTRODUCTION

British Columbia has varied and complex geography and the forecasted climate changes across the province are equally varied and complex. Climate change models for B.C. forecast 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, and more frequent 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, Natural Resource Operations and Rural Development (FLNR) 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.

The management of resource roads and infrastructure continues to be an important activity for industries and governments across Canada. The planning, construction, and maintenance of resource roads are required to support various industrial and resource management activities and are often the primary access for remote communities and public recreational experiences.

Given the significance that resource roads contribute to economic and social well-being, efforts are required to understand the implications of climate change in order to adapt roads and infrastructure to the impacts of climate change.

The adaptation of resource roads and infrastructure to climate change involves understanding risks and vulnerabilities, identifying infrastructure components where risks are greatest, and creating a strategy to ensure that the road and infrastructure components are made resilient.

In order to advance the understanding of the vulnerabilities of resource roads to climate change, and to identify measures to mitigate impacts, FPInnovations partnered with FLNR to conduct a risk and vulnerability assessment case study of the Willow Forest Service Road (FSR) located southeast of Prince George, B.C.

Project objective

The principal objectives of this assessment were to:

- Evaluate the risks and vulnerabilities to climate change of the infrastructure on the Willow FSR.
- Refine the PIEVC approach for application to resource roads.
- Derive general conclusions about the vulnerabilities and risks to climate change of resource road infrastructure.

Study scope and timing

The scope of the assessment included the current design, operation, and management of the resource road infrastructure along the 92 km-long gravel surfaced length of the Willow FSR, from KM 7 to KM 99.

The assessment considered the climate change effects for two climate periods (1) baseline condition defined as the period of 2011-2040, and (2) future condition defined as the period of 2041-2070. The period of 2041-2070 was chosen because the general lifespan and planning period of a resource road and its infrastructure components is approximately 30 years.

About the PIEVC protocol

A variety of management processes are available to assess the vulnerability of engineered structures to climate change; however, a method commonly used in Canada is the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (Engineers Canada 2016). The PIEVC protocol is a civil engineering tool used to assess the vulnerability of engineered structures to climate change. A variety of data are required to conduct a vulnerability analysis including infrastructure age, condition and inspection data, traffic volumes, geotechnical and terrain information, and data about extreme weather events and their impact(s) on infrastructure.

The PIEVC has created a five-step protocol to assess various infrastructure components, while focused on public and civil infrastructure; it also can be adapted to resource roads and infrastructure (figure 1). The PIEVC protocol reviews historic climate data and projects the nature, severity, and probability of future events for a specific region. This information is then used to conduct a risk assessment of existing or planned infrastructure to determine if and what management response is required. This also provides managers and planners an opportunity to understand and establish the adaptive capacity of infrastructure, as determined by design, operations, maintenance, and policies.

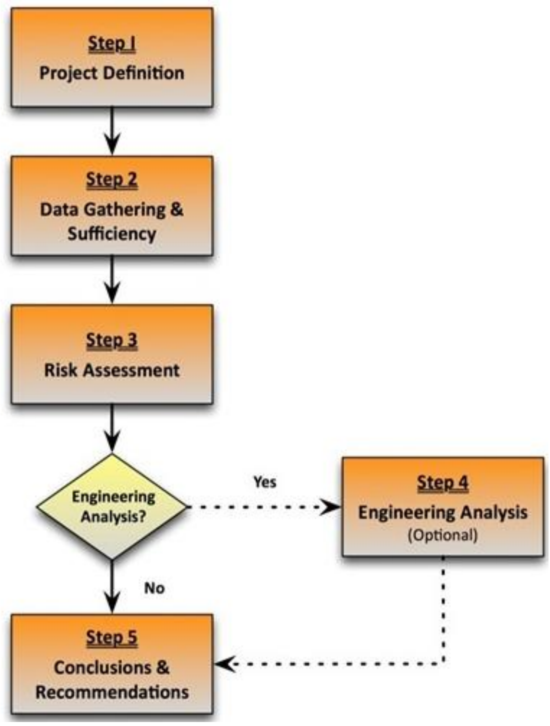

Figure 1. Stages in the PIEVC protocol. Reproduced from Engineers Canada 2016.

Step 1 - Defining the scope of the risk and vulnerability assessment is a crucial first step in ensuring that the analysis is effective, and that the conclusions and recommendations are relevant to the project objectives. The project definition includes identifying items such as the road segments to be studied, and stakeholders and road users to consult or consider.

Step 2 - During the data gathering and sufficiency step, it is important to consider which types of road and infrastructure components to gather data on (e.g., bridges, road surfacing, cut slopes), and which weather events historically occur in the area and directly influence the road and infrastructure components in strongly negative ways.

Step 3 - In the risk assessment step, climate parameters are selected which characterize the climatic changes of concern. Climate models, with assumptions for various climate change scenarios, are run for the subject area and downscaled to provide localized forecasts of the frequency and intensity of future weather events and climatic conditions on a local basis. The climate parameters of interest are then derived from these forecasts. A high-level risk assessment is made for each infrastructure element identifying which, and by how much, each climate parameter is likely to influence the performance of each type of road and infrastructure

Step 4 – If a type of infrastructure is found to be at high risk, an engineering analysis may be initiated. The engineering analysis step has various components, including verifying and refining the climate forecasts, and assessing load capacity vulnerability. Those familiar with the design of the infrastructure elements review the design assumptions, material properties, etc. to assess the anticipated changes in performance given the climate changes anticipated. If design changes are warranted to ensure safety or reliability, then these are recommended.

Step 5 – The final step is the development of conclusions and recommendations in respect to possible operational or management actions required to upgrade the infrastructure. The overall resiliency and vulnerability of the infrastructure to climate change is described as well as any need to conduct additional analysis or further data gathering.

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 Willow FSR.

The assessment team for this project provided the principle work and efforts required in completing the numerous steps, information gathering, and data development to ensure completion of the assessment. The members of the assessment team are listed in table 1.

Table 1. Assessment team members

Team Member	Position	Organization	Role
Allan Bradley	Lead Researcher	FPInnovations	Team Lead
Mark Partington	Senior Researcher	FPInnovations	Team Lead
David Spittlehouse	Climatologist	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Climate analysis
Trevor Murdock	Lead – Regional Climate Impacts	Pacific Climate Impacts Consortium	Climate analysis
Keith Taite	Planning Forester	Carrier Lumber Ltd.	Road use and management - industry
Daniel Burri	Engineering Officer	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Road use and management – government
Brian Chow	Chief Engineer	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Engineering and design – provincial level
Jason Olmsted	Northern Engineering Group Leader	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Engineering and design – regional level

The advisory team participated in the pre-workshop field visit and the vulnerability assessment workshop. They 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 table 2.

Table 2. Advisory team members

Team Member	Position	Organization	Role
Matt Campbell	FPInnovations Coordinator	Canfor Corp.	Road use and management – Industry
Vanessa Foord	Climatologist – Omineca, NW & NE	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Climate analysis
David Belyea	Industry Advisor – Northern Interior	FPInnovations	Observer
Jim Barnes	Manager, Corporate Initiatives	B.C. Ministry of Transportation and Infrastructure	Observer

STEP 1 – PROJECT DEFINITION

This section outlines the project parameters for each of the infrastructure and climate components.

General description of the infrastructure and site

The Willow FSR starts within the city limits of Prince George, B.C. and terminates at an approximate distance of 99 km at a recreation site on Stony Lake (figure 2). The scope of this assessment includes the entire unpaved length of the road starting at KM 7 and ending at KM 99. This road is locally referred to as the Willow FSR and is comprised of the Willow Cale FSR from KM 7 to KM 21.5, Buckhorn Lake Road from KM 21.5 to KM 41.7, and the Willow - Thursday Creek FSR from KM 43.5 to KM 99. The Willow Cale was built in the 1960s using bulldozers and an overlanding technique (fill placed on log corduroy). Bridges on the Willow FSR network of roads are designed to an L-100 rating to support off-highway log truck loads.

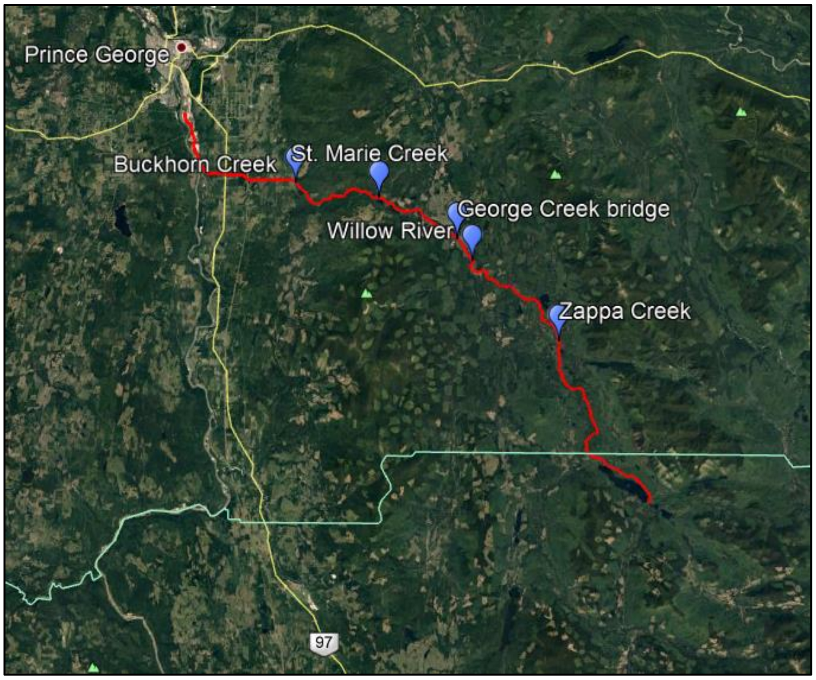

Figure 2. Willow Forest Service Road area of study.

The Willow FSR follows the Fraser River south until approximately KM 10 and then heads due east away from the river across the Fraser River flood plain. This section of the FSR is underlain by a deposit of plastic clay (the Pine View clay seam). There is a long gentle grade near KM 11 that the road climbs as it leaves the immediate vicinity of the Fraser River to intersect with Highway 97. An industrial park is located along the first 7 km of the FSR, and there is heavy industrial traffic using the roadway between this complex and Highway 97.

From KM 12 to KM 22 is a small but growing farming community named Buckhorn Lake. Carrier Lumber has observed an increase in wet road failures (in-road springs, rutting, deep rut subgrade failures, erosion at stream crossing structures) in this section of the Willow FSR which may be in part attributed to the possible increased runoff from the expanding agricultural lands. Starting at KM 21, the road enters rolling hills, skirting south around Tabor Mountain as it follows the wetland drainage of Buckhorn Creek. At approximately KM 25, the road begins gently climbing (figure 3). Tabor Mountain has a large recreational complex. The section of the FSR between KM 12 and KM 25 experiences heavy use by residents and recreational users.

Figure 3. Willow Forest Service Road elevation profile for the area of study.

From KM 35 to KM 39, the FSR passes through a lake complex (Francis Lake, Ste. Marie Lake, Opatcho Lake). It crosses bridges at Thursday Creek (KM 46) and George Creek (KM 47.5). The FSR follows the Willow River southeast for about 10 km until it crosses the river on the Willow River bridge (KM 51.4). Between KM 7 and KM 51 the stream crossing infrastructure includes a large diameter, double culvert near KM 35.2 (Ste. Marie Lake), five short single span bridges, and the two large multi-span bridges at George Creek and Willow River. Additionally, there are bridges located close to the Willow FSR where it branches onto the Willow-Stone Buck FSR (KM 25.4) and onto the Hansard FSR (KM 41.7).

East of the Willow River, the FSR climbs to a plateau and follows it southeast where it passes numerous small lakes (e.g., Ispah Lake, Pitoney Lake, Doe Lake). The FSR crosses single span bridges at Zappa Creek (KM 70) and Narrow Lake Creek (KM 72.6). Near KM 75, the road again approaches the Willow River and follows it southward – staying on the high ground to the east. When the FSR reaches Stony Lake, it follows the eastern shoreline to the Stony Creek Recreation Site at the southern tip. The Willow FSR terminates at the southern tip of the lake on the Stephanie Creek bridge (KM 99). From KM 51 to KM 99, the Willow FSR is of a lower standard, has much less traffic, and is not maintained as actively.

The local road users expressed that cross-drain frequency and sizing are issues along the entire FSR, and cross drains commonly experience blockages from laminar ice buildup and from beaver activity. The change from traditional, concentrated, operating areas to dispersed harvesting patterns has eroded the ability of licensees and FLNR to fund adequate levels of road maintenance. This has resulted in a general degradation of local road conditions (i.e., overwide and insufficiently crowned roads, suboptimal grading practices, brushed in right-of-way, and poorly draining ditches) as was observed during the field visit conducted by the assessment team.

Historic extreme weather-related observations

One of the earliest noted extreme weather-related events on the Willow FSR was a washout of the George Creek bridge in 1990. The eastern abutment was eroded when a debris plug directed heavy flow towards the bank. The debris and the heavy flow occurred in an extreme flood event preceded by a heavy rain-on-snow event in early May. At the time of the washout, the bridge had been in place for over 30 years; and, was subsequently replaced by a multi-span bridge with more clearance for high flows and debris. This event was particularly notable for the loss of life that occurred when a van occupied by six tree planters plunged into the river before the bridge washout was known and barriers erected.

In 1997, two separate rain-on-snow events at the end of April and then, again, in early May resulted in numerous culvert washouts, road shoulder erosion, and general flooding at many locations along the length of the Willow FSR.

The Zappa Creek crossing located at KM 70 has had performance and maintenance challenges documented since 1997. These issues are mainly attributed to bedload and debris mobilized by flood events and damming the crossing location. With climate changes, such as atmospheric rivers ('Pineapple Express' events) now reaching Prince George, issues with debris and bedload accumulation can be expected to become more common. In 1997, heavy runoff washed out the battery of four culverts and the channel became unstable. In 1998, there were erosion issues with the repaired culverts. In 2000, the culverts were replaced with an 18 m-long bridge to try and alleviate the performance concerns, however, flood events in 2001 created a log jam downstream of the crossing and, in subsequent floods, backwatering caused by the log jam led to deposition of bedload at the crossing. In 2002, the streambed was dredged at the crossing to re-establish bridge clearance but applications to remove the downstream log jam were not approved. In 2003, an upstream log jam causing channel erosion and shifting had to be removed. In 2004, the bridge was raised by approximately 1 m. In 2005, the river cut a new channel around the downstream log jam and this increased the stream gradient and eliminated the backwatering problems. No further performance issues have been reported.

In 2011 and 2012, heavy spring flow caused movement of a braided section of the channel of Buckhorn Creek (near KM 22). The creek eroded its streambank and about 1.5 m of the adjacent FSR embankment where it runs beside the creek. To repair the road and prevent future erosion, about 1 km of the FSR was realigned 5 m back from the streambank, and the streambank was lined with large riprap. As a proactive measure to protect other sections of the road that are located close to the braided stream channel, an erosion barrier of coarse riprap and woven geotextile was constructed in a trench excavated outside of the ditch line.

During the same 2001 storms, a substantial amount of debris was mobilized by channel erosion and this caused a major logjam to form under the Willow River bridge. A rapid response was required to prevent bridge damage. Subsequently, rock groins were installed upstream of the bridge to reorient floating debris to more readily pass the bridge. Figure 4 illustrates a similar minor logjam observed during the 2018 field tour.

Figure 4. Minor logjam in July 2018 rests against guard piles of Willow River bridge (KM 51.4).

The local road users indicated that large (e.g., 20° C) temperature swings in recent winters have resulted in icy, unsafe road conditions on the FSR and associated road network. The ice build-up (‘glaciation’) occurs when localized snowmelt and (or) rainfall flows onto the road and refreezes. Glaciation is especially prevalent where dips in the road are exposed to sunshine and near ice-blocked cross drains and this was expressed as a reoccurrence with the culvert at KM 20.5. Glaciation can also occur in spring when water from melting snow berms is prevented from draining off the road surface by the roadside snow berms and a flat crown established for winter.

Rain when temperatures have risen above 0°C can rapidly create unsafe conditions. In January 2017, rain during a mid-winter warm spell froze on the road surface and created icy, unsafe conditions. There was a collision near the intersection with Highway 97 (Figure 5). Trucks also had difficulty negotiating KM 11 hill and so industrial traffic was redirected onto Damms Road until conditions improved. In recent years, rain during mid-winter warm spells has occurred 1 to 2 times per winter.

Figure 5. Rain during a warm spell in January 2018 resulted in icy road conditions and a vehicle collision on the Willow FSR near Highway 97 (photo courtesy of Carrier Lumber).

With surface melting, pot holes develop and applied sand sinks into the icy surface and becomes ineffective. This requires an increased maintenance response but is easily handled. Additionally, the increased risk from icy road conditions has forced forest companies to switch from using provincial ambulances to using industrial ambulances that are equipped with tire chains.

In recent years, some B.C. forest companies have tried extending operations into the late fall and the spring-thaw period in order to compensate for climate change caused haul interruptions in the rest of the year. Shorter winters, more frequent wet-weather shutdowns, longer fire seasons, and longer haul distances due to dispersed harvest of mountain pine bark beetle-killed timber and wet weather reducing the amount of dry summer harvest areas close to Prince George is challenging the traditional forest haul schedules. Construction or use of resource roads in the shoulder seasons, when wet conditions prevail, can be problematic. For example, springtime hauling results in heavy trucks using resource roads when they are thaw-weakened and most vulnerable to deep surface rutting and related subgrade failures. There is concern that the use of full truck weights on thaw-weakened resource roads could cause rapid, widespread destruction of these assets, with an associated loss of service and road reconstruction cost.

An example of road destruction caused by a concentrated industrial haul during the spring-thaw period occurred on the Willow FSR in spring 2018. From 2017 until mid-2018, access to the Willow FSR industrial park from the north was blocked for reconstruction of the Haggith Creek bridge. This forced local traffic, including chip and lumber trucks, to use the Willow FSR to reach Highway 97 and Prince George. During the spring thaw, considerable rutting and deep subgrade failures occurred just east of the railway crossing (KM 9.6) and on the long flat stretch to the hill (KM 10 to KM 10.5). The rough conditions made it especially difficult for the low clearance chip trucks. Also, moderate rutting and slippery conditions formed on the KM 11 hill, where poor drainage conditions concentrated water on the road.

In late spring 2018, Carrier Lumber reconstructed the damaged sections of the Willow FSR. The repair procedure included deep excavation and replacement of the heavy clay subgrade, which becomes saturated and weak during spring thaw, with a free-draining subbase layer of coarse aggregate sandwiched between layers of woven geotextile (Figure 6).

Figure 6. Reconstruction on the KM 11 hill of the Willow FSR with a free-draining subbase (photo courtesy of Carrier Lumber).

Climate parameter identification

The eleven climate parameters that were included in the risk analysis are presented in table 3. The assessment team started with a list of climate events that were analyzed in previous PIEVC assessments on resource roads in British Columbia (Bradley & Forrester 2018; Partington et al. 2018), and the list was modified to include those that were determined to be most relevant to this assessment.

Table 3. Climate parameters used for the assessment

Climate parameter	Definition – threshold	Relevance to the infrastructure component
Drought conditions	Days with drought code from very high to severe	Wildfire hazard, increased runoff from hydrophobic soils, road dust conditions
Extreme high rainfall in 24-hour period	1 in 100 year wettest 1-day precipitation	Extreme high runoff. Culvert and bridge damage or destruction, road surface damage or deterioration, safety.
High rainfall in 24-hour period	1 in 20 year wettest 1-day precipitation	High runoff. Culvert and bridge damage or destruction, road surface damage or deterioration, safety. Impacts to smaller basins.
Sustained rainfall	Annual maximum consecutive 5-day precipitation	High runoff. Culvert and bridge damage or destruction, road surface damage or deterioration, safety. Impacts to larger basins and watercourses.
Antecedent rain followed by significant rain event	14-day antecedent rainfall >70 mm followed by 1-day rainfall > 1 in 20 year 1-day rainfall (35 mm for region)	High runoff and saturated soils. Impacts to cut/fill slopes, landslides. Culvert and bridge damage or destruction, road surface damage or deterioration, safety.
Freeze/thaw cycling	Days when T_{max} > 0 °C and T_{min} < 0 °C	Laminar ice build-up (glaciation) occurs on watercourses, ditches, and onto roads; preventing function
Freeze/thaw 2	Greater than 10 occurrences of the frequency of days in a row > 3 and T_{min} > 0 °C (November – March, precipitation implied)	Loss of road integrity through soft road prism conditions, increased soil moisture conditions
Spring thaw	Thawing index; Cumulative Thawing Index (CTI) > 15-degree days	Weak and thawing road conditions, deep subgrade failures created by heavy trucks.
Rain on snow	Days per year with 2-day rain > 35 mm and snow pack > 35 cm deep	Increased runoff and peak streamflow
Rapid snow melt	1-day snow melt > 30 mm	Spring freshet conditions causing runoff and peak streamflow. Culvert and bridge damage or destruction, safety.
Snow frequency	Days with > 10 cm of precipitation as snow (T_{avg} < 1 °C)	Snow plowing resulting in increased risk to damage of infrastructure.

Drought code is a component of the Canadian Forest Fire Weather Index System. It is evaluated using the factors of temperature and rain with a daily rating ≥ 300 indicating a very high to severe drought. The assessment team attempted to evaluate the impacts of a wildfire on its own, but the idea was rejected as it was not in itself a climate event. The decision was made that it would be included under the drought conditions event which is based on the drought code, a numeric rating of the dryness of deep organic soil horizons.

Spring thaw was considered in the assessment and is not in itself a climate event, but it is modelled using the cumulative thawing index (CTI). CTI is used as a threshold to initiate spring load restrictions (SLR) in various jurisdictions in North America. A CTI value of 15 degree-days was chosen for use in this assessment because this is a typical threshold used for starting SLR.

Site visit

A field review of the Willow FSR was conducted on July 17th 2018, the day prior to the assessment workshop. The field visit provided the assessment and advisory teams the opportunity to view the road study area, visit road locations and infrastructure where historical and (or) current performance and maintenance issues exist, and to discuss risk mitigation and climate change adaptation practices to consider.

The field visit provided the opportunity for the entire assessment and advisory teams to align their expertise and contributions to the vulnerability assessment workshop with the operational needs and experience of the local road users and managers.

STEP 2 – DATA GATHERING AND SUFFICIENCY

Identification of applicable infrastructure components

The types of infrastructure and operational considerations that were considered in the risk analysis are presented in table 4. Included in the table are projected impacts of a failure on component condition and function.

Infrastructure components were divided into three categories:

- Road features, including the road prism, cut and fill slopes, cross drains, and ditches.
- Stream crossings, including bridges and other major structures (e.g., culverts and arches), and minor structures (i.e., other culverts).
- Operational considerations, including access, emergency response, winter and summer maintenance/construction, and safety.

Table 4. List of infrastructure components used in the assessment

Infrastructure components and operational considerations	Description of infrastructure components	Impact of failure
Road features		
Road prism (surface/subgrade)	Running surface, road shoulders, subgrade	Failures affect road functionality, maintenance, safety, etc.
Cut and fill slope	Constructed slopes beside road	Failures affect road function, maintenance, drainage, and can propagate to areas uphill or downhill
Ditches	Water drainage ditches alongside the road	Failures affect road function, maintenance, drainage, and downhill slope stability
Cross drains	Culverts in road to drain ditch water to opposite side of road	Failures affect road function, maintenance, drainage, and downhill slope stability
Stream crossings		
Major culverts > 2.0 m	Culvert diameter of 2.0 m or larger	Flooding, road prism washouts, structure loss, road closure
Other culverts < 2.0 m	Culvert diameter less than 2.0 m	Flooding, road prism washouts, structure loss, road closure
Bridges	All bridges	Road approach washouts, structure loss, road closure
Operational considerations		
Commercial, recreational, residential access	All industrial traffic, light recreational and residential vehicles	Access restricted
Emergency response	Emergency response vehicles, ground transport	Access restricted, health risk
Winter maintenance & construction	Plowing, grading, sand, culvert de-icing (frozen conditions)	Winter maintenance/construction response (costs, effort) increased
Summer maintenance & construction	Grading, dust abatement, ditch cleaning, brushing, construction (unfrozen conditions)	Summer maintenance/construction response (costs, effort) increased
Safety	Light vehicles, maintenance vehicles	Access restricted, road user safety compromised

Identification of applicable climate information

The assessment team engaged the Pacific Climate and Impacts Consortium (PCIC) to develop the climatic data projections for the study area. A further analysis and climate variable development and interpretation was then performed by David Spittlehouse, FLNR climatologist, based on the climatic data projections.

A polygon enclosing the 92 km length of the road by 30 km wide centered on the road was used by PCIC to define the area of interest for the spatial climate summaries.

With those data, different climate change scenarios were selected in order to provide a wide spread in projected future climate for calculating specific variables for the PIEVC protocol analysis.

An example of climate variation within the study area is shown on figure 7. Such a variation in precipitation is mainly due to the change in elevation across the study area rather than a north-south gradient.

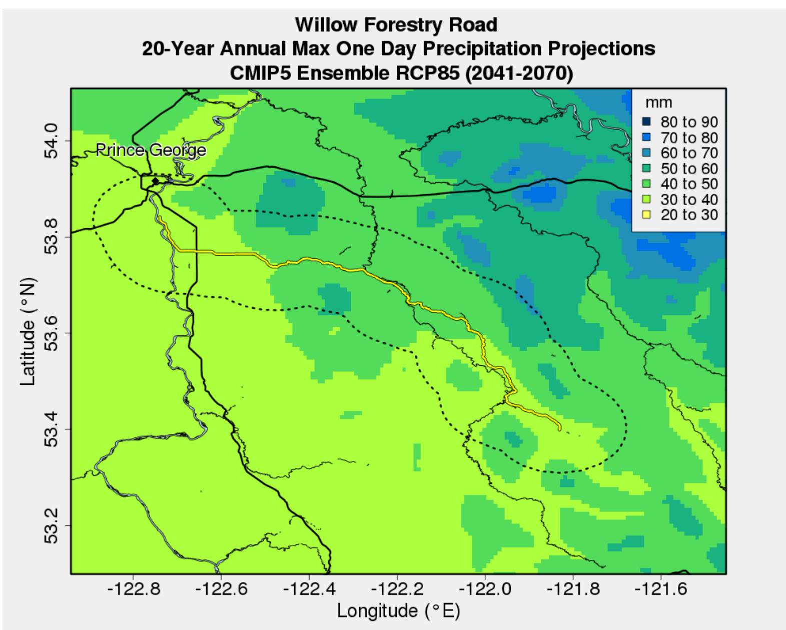

Figure 7. 1 in 20 year maximum 1-day precipitation, for the 2041-2070 period, for the Willow FSR (yellow line) study area (area bounded by dashed line).

In summary, the climate modelling and analysis highlighted the following results:

- Warming is projected to occur in all seasons, with the average annual temperature increasing by 3°C by the 2050's (2041-2070 period).
- The 20-year return period daytime-high temperature is forecasted to increase by 5°C, and the nighttime-low temperature by 6°C.

- Summer precipitation is forecast to remain the same or slightly decrease. Winter precipitation is forecast to increase by 6%; and, spring and fall are forecast to increase by 16%.
- The 20-year return period annual maximum 1-day and 5-day precipitation are projected to increase by 13-15% by the 2050's (2041-2070 period).
- A warming winter means that there will be an increase in winter streamflow, an earlier melt season, and the potential for increased size of snow-melt-driven peak flows.

Projected data were calibrated using data from the 1971-2000 period. With a downscaled global climate model (GCM) using daily weather data from the past, data for two distinct, 30-year periods were projected:

- 2011-2040, and
- 2041-2070

The future condition considered in this assessment was based on data from the 2041-2070 period. This period was chosen because it represents the common service life of resource road infrastructure.

Different climate parameters were analyzed using modeled temperature and precipitation data but only those that are relevant to the road infrastructure were kept in the risk analysis (table 5).

Table 5. Climate parameters used for the baseline and future periods

Climate Component	Definition	Data source	Current (2011-2040)	Future (2041-2070)
			Value	Value
Drought conditions	Days with drought code from very high to severe	Custom	65 days (1 in 20 return period)	65 days (1 in 20 return period)
Extreme high rainfall in 24-hour period	1 in 100 year wettest 1-day precipitation	Custom	50 mm	63 mm
High rainfall in 24-hour period	1 in 20 year wettest 1-day precipitation	PCIC climdex - RP20PR	35 mm	42 mm
Sustained rainfall	Annual maximum consecutive 5-day precipitation	PCIC climdex – RX5day	58 mm	65 mm
Antecedent rain followed by significant rain event	14-day antecedent rainfall > 70 mm followed by 1-day rainfall > 1 in 20 year 1-day rainfall (35 mm for region)	No data	No data	No data
Freeze/thaw cycling	Days when T_{max} > 0 °C and T_{min} < 0 °C	Custom	110	82
Freeze/thaw 2	Greater than 10 occurrences of the frequency of days in a row > 3 and T_{min} > 0 °C (November – March, precipitation implied)	No data	No data	No data
Spring thaw	Thawing index; Cumulative Thawing Index (CTI) > 15-degree days	Custom	Day of year = 127 ± 20	Day of year = 115 ± 20
Rain on snow	Days/year with 2-day rain > 35 mm and snow pack > 35 cm deep	Custom	1 in 25 return period	1 in 15 return period
Rapid snow melt	1-day snow melt > 30 mm	Custom	1 in 30 return period	1 in 27 return period
Snow frequency	Days with > 10 cm of precipitation as snow (T_{avg} < 1 °C)	Custom	7 days (1 in 20 return period)	6 days (1 in 20 return period)

The assessment team reviewed the available data, weather events of interest, and climate parameters used in previous PIEVC assessments on resource roads to arrive at the final climate parameter list. Suitable climate data was available to provide values for all but two of the climate parameters:

- Antecedent rain followed by a significant rain event
  - The assessment team felt that the occurrence of heavy rain on saturated soils could create conditions that would negatively impact the infrastructure. However, it was found to be difficult to define the condition and thresholds to include in the assessment and to develop climate data to support this parameter.
- Freeze/thaw 2
  - The assessment team identified this parameter as a means in which to capture extended warm periods in winter when precipitation occurs. The team was unsure of how to define the threshold level and had researched alternative indicators such as the number of accumulated degree days above 0°C and the number of days above 0°C in January through March but did not see a trend or link to local historical observations. It was felt that given the recent historical events and consideration of other data included in this assessment that it was valuable to keep in the assessment. The impacts of this parameter were considered to significant negative impact on road usage due to loss of road integrity through soft road prism conditions.

Given the time and budget constraints of the assessment, the team was unable to identify data and values for these two parameters. The assessment team was concerned enough about the possible risks presented by these parameters, however, for them to be kept in the assessment. The knowledge and experience of the assessment team and the interpretation of the climate data available for the other climate parameters was used to assign probabilities scores for these two parameters.

STEP 3 – RISK ASSESSMENT

The assessment and advisory teams met on July 18th, 2018 in Prince George, B.C., to review the climate modelling, to determine the applicable infrastructure components, and to assign severity and vulnerability scores, as necessary, to perform the risk assessment. This working meeting was led and facilitated by FPInnovations who provided direction throughout the process of applying the PIEVC protocol. At the conclusion of the 1-day meeting, scores for severity and vulnerability had been assigned for all interactions in the baseline period of the assessment and some of the future period interactions also. Based on this work, FPInnovations, in consultation with the assessment team, completed the scoring after the workshop.

Risk assessment spreadsheet

The assessment team used a spreadsheet to assess risks and vulnerabilities and to identify the interactions between infrastructure components and climatic events. The content of the spreadsheet is presented in the following sections.

SPREADSHEET FORMAT

The spreadsheet is structured as a matrix in which the rows are infrastructure components and columns are the climate parameters. To assist the team to identify the most important responses of each infrastructure component, the table included performance response considerations for each type of infrastructure. The probability, severity, and risk scores are tabulated in the risk analysis field (figure 8).

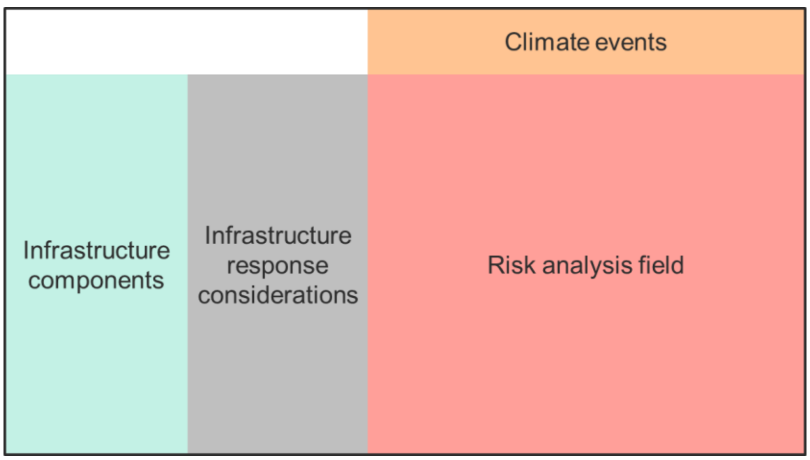

Figure 8. Schematic of spreadsheet used in the risk assessment.

INFRASTRUCTURE RESPONSE CONSIDERATIONS

The infrastructure response considerations in the risk assessment spreadsheet were not populated by the assessment team. Due to the relatively short list of infrastructure components considered in this assessment, the high-level approach taken for the study, and the team's high degree of familiarity with the road, the assessment team chose not to formally document the infrastructure response considerations.

The contribution of each component to the risk analysis was well understood and was considered when assigning the probability and severity scores.

YES/NO ANALYSIS

In this preliminary stage of the assessment, the assessment team judged whether the infrastructure component interacts with the climate event. 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.

In this study, it was found that every road feature and stream crossing component was exposed to climate events. The only occurrences where some interactions were not assessed were when a seasonal climate event and a seasonal operational consideration occurred, such as summer or winter maintenance and construction. Out of a total of 132 possible interactions (12 infrastructure components and 11 climate events), 11 interactions were withdrawn from the yes/no analysis, for a total of 121 interactions to assess.

PROBABILITY SCORES

In the risk assessment, the practitioner must assign a probability value to indicate if a certain weather event will exceed infrastructure thresholds. The team had access to climatic data for many of the climate parameters chosen for this assessment and some of the values were reported in terms of return period, other events as annual values (mm or days) while two parameters did not have supporting climate data.

To assess probability (Table 6), the protocol uses a standardized scale of scores from 0 to 7, with 0 representing that the event will not occur and 7 representing that the event will occur. The team had the option to choose between two methods within the PIEVC protocol to assign probability:

- Method A, which is more qualitative, and;
- Method B, which uses an annual probability of an event happening.

Table 6. PIEVC protocol definitions of probability

Score	Probability	
	Method A	Method B
0	**Negligible** **Not applicable**	< 0.1 % < 1 in 1,000
1	**Highly unlikely** **Improbable**	1 % 1 in 100
2	**Remotely possible**	5 % 1 in 20
3	**Possible** **Occasional**	10 % 1 in 10
4	**Somewhat likely** **Normal**	20 % 1 in 5
5	**Likely** **Frequent**	40 % 1 in 2.5
6	**Probable** **Very frequent**	70 % 1 in 1.4
7	**Highly probable**	> 99 %

In the case of this assessment the team used Method A as a reflection of the availability and type of data available. Probability scores were determined for the baseline and future period (table 7). The team assigned probability scores based on the PIEVC protocol approach where scores are assigned based on the probability of the climate parameter triggering infrastructure thresholds both for the baseline and future climate.

Table 7. Climate parameters and their assigned probabilities for current and future periods

Climate component	Definition	Baseline (2011-2040)	Future (2041-2070)
		Score	Score
Drought conditions	Days with drought code from very high to severe	2	2
Extreme high rainfall in 24-hour period	1 in 100 year wettest 1-day precipitation	4	5
High rainfall in 24-hour period	1 in 20 year wettest 1-day precipitation	2	3
Sustained rainfall	Annual maximum consecutive 5-day precipitation	2	3
Antecedent rain followed by significant rain event	14-day antecedent rainfall > 70 mm followed by 1-day rainfall > 1 in 20 year 1-day rainfall (35 mm for region)	1	1
Freeze/thaw cycling	Days when T_{max} > 0 °C and T_{min} < 0 °C	7	7
Freeze/thaw 2	Greater than 10 occurrences of the frequency of days in a row > 3 and T_{min} > 0 °C (November – March, precipitation implied)	4	6
Spring thaw	Thawing index; Cumulative Thawing Index (CTI) > 15-degree days	7	7
Rain on snow	Days per year with 2-day rain > 35 mm and snow pack > 35 cm deep	4	5
Rapid snow melt	1-day snow melt > 30 mm	2	2
Snow frequency	Days with > 10 cm of precipitation as snow (T_{avg} < 1 °C)	3	2

SEVERITY SCORES

In order to assess risk, the second step is to assess the consequences of a climate event happening on the infrastructure components. Unlike probability, severity scores are not based on specific models; practitioners must rely on their experience, expertise, and knowledge of the subject road to ensure a reasoned, reliable severity rating of climate impact on each type of the infrastructure. Severity scores provide an indication of how the infrastructure's serviceability, capacity, function, and service life are impacted by a climate parameter, and how costly and problematic the management response(s) are.

Similar to that used in the probability rating, a scale of 0 to 7 is used for scoring severity. A score of 0 indicates no negative consequences, and a score of 7 indicates that the infrastructure element will catastrophically fail resulting in extreme consequences to road users, should the climate event occur. The PIEVC protocol offers two severity rating methods - method D and method E, - and these are shown in table 8.

Table 8. PIEVC protocol definitions of severity

Score	Severity of consequences and effects	
	Method D	Method E
0	No effect	**Negligible** **Not applicable**
1	Measurable	**Very Low** **Some measurable change**
2	Minor	**Low** **Slight loss of serviceability**
3	Moderate	**Moderate loss of serviceability**
4	Major	**Major loss of serviceability** **Some loss of capacity**
5	Serious	**Loss of capacity** **Some loss of function**
6	Hazardous	**Major** **Loss of function**
7	Catastrophic	**Extreme** **Loss of asset**

For this assessment, method E was used because it was judged by the assessment team to be more accurate, robust, and rigorous. Each of the 121 interactions was assigned a severity score; scores were based on the assessment team's experience and professional judgment.

RISK SCORES

Once the probability and severity scores are assigned, it is possible to determine the risk of each interaction of climate event and infrastructure component. The PIEVC protocol defines risk as follows:

$$R = P * S$$

where risk (R) is the product of the probability (P) of an event occurring and the severity (S) of that event, should it occur. Nodelman (2017) describes risk as "an estimate of the seriousness of a vulnerability response of an asset to an anticipated weather event". The result of the product of the probability score and the severity score produces a risk score, which can range from 0 (no risk) to 49 (highest risk possible).

The PIEVC protocol provides direction for the application of risk tolerance thresholds of high, high-medium, low-medium, and low. The assessment team adopted this framework for application in this study (table 9).

Table 9. Risk tolerance thresholds and color codes

Threshold	Risk range	Response
Low	< 13	No action required
Low-Medium	13 - 25	Remedial actions may be required
High-Medium	26 - 36	Remedial actions may be required
High	>36	Immediate action required

The risk thresholds can be adapted to each project; it is the responsibility of the assessment team to decide what the risk tolerance is. In this study the assessment team adopted both the low-medium and the high-medium thresholds to highlight changes in risk from the baseline and future climate periods.

Risk score analysis

A risk score analysis as determined by the assessment team is presented in table 10 for the baseline period, which represent the current risk, and for the forecasted climate condition in the period from 2041 to 2070.

Table 10. Summary of risk scores for baseline (B = 2011 to 2040) and future (F = 2041 to 2070) periods.

Infrastructure components	Drought		Extreme high rainfall in 24 hr period		High rainfall in 24 hr period		Sustained rainfall		Antecedent rain followed by significant rain event		Freeze-thaw cycling		Freeze / thaw 2		Spring thaw		Rain on snow		Rapid snow melt		Snow frequency	
Baseline / Future	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F
Road features																						
Road prism	6	6	12	15	4	6	6	9	5	5	21	21	24	36	42	42	20	25	10	10	3	2
Cut fill and slope	4	4	12	15	4	6	6	9	5	5	14	14	8	12	7	7	20	25	10	10	3	2
Ditches	0	0	16	20	6	9	6	9	5	5	35	35	12	18	7	7	24	30	12	12	3	2
Cross drains	2	2	16	20	4	6	6	9	5	5	35	35	20	30	7	7	24	30	12	12	3	2
Stream crossings																						
Major culverts >2.0m	2	2	8	10	2	3	4	6	3	3	7	7	4	6	7	7	8	10	4	4	3	2
Other culverts <2.0m	2	2	16	20	4	6	8	12	5	5	28	28	12	18	7	7	20	25	10	10	3	2
Bridges	12	12	8	10	2	3	4	6	3	3	7	7	4	6	7	7	8	10	4	4	3	2
Operational considerations																						
Commercial, recreational, residential access	8	8	12	15	2	3	6	9	5	5	42	42	24	36	35	35	20	25	10	6	9	6
Emergency response	12	12	12	15	2	3	6	9	5	5	28	28	24	36	35	35	20	25	10	10	9	6
Winter maintenance & construction	na	na	na	na	na	na	na	na	na	na	21	21	24	36	28	28	24	30	12	12	9	6
Summer maintenance & construction	12	12	12	15	2	3	6	9	5	5	na	na	na	na	na	na	na	na	na	na	na	na
Safety	10	10	8	10	4	6	6	9	5	5	35	35	24	36	28	35	24	30	12	12	12	8

Discussion

The assessment team evaluated risk on 121 potential climate and infrastructure interactions for the baseline and future assessment periods. As a result of the assessment. it is anticipated that there will be a reduction in low risk interactions and an increase in high-medium risk interactions in the future (Table 11).

Table 11. The number of baseline and future risk interactions for each risk tolerance threshold

Threshold	Baseline (2011-2040)	Future (2041-2070)
Low	89 (74%)	82 (67%)
Low-Medium	21 (17%)	18 (15%)
High-Medium	9 (7%)	19 (16%)
High	2 (2%)	2 (2%)

BASELINE (2011-2040) PERIOD

The assessment team determined that the highest risk scores were associated with the climate parameters spring thaw and freeze/thaw cycling. These climate parameters were found to present the highest risk to the road prism and commercial, recreational, residential access. These high ratings reflect the concerns and comments from local road users about maintenance interventions that have occurred in recent years where failures in the road surface and subgrade have occurred due to soft road material conditions.

The high-medium risk category was found to occur with the freeze/thaw cycling and spring thaw climate parameters although each was determined to impact different infrastructure categories. Freeze/thaw cycling promotes ice buildup that may block ditches, cross drains, and stream-crossing structures. Freeze/thaw cycling has occurred on the Willow FSR in recent years and this has blocked several smaller culverts with laminar ice build-up. When fully or partially blocked, these culverts become incapable of passing water and, when further freeze/thaw cycling occurs, the resulting snowmelt can flow over the road and freeze or can washout the blocked culvert. Both icy road conditions and washed out culverts are considered high-medium risk conditions, with respect to road user safety and emergency response.

The spring thaw climate parameter, represented by the Cumulative Thawing Index, highlights the risks created by weak and thawing road conditions, and the risk of deep subgrade failures created by heavy truck traffic. These conditions impact road access (all categories), road user safety, and winter maintenance & construction. The performance of the road during warmer winters has been a primary concern of local road users for several years.

FUTURE (2041-2070) PERIOD

The future period showed an increase in the number of medium-high risk ratings for the freeze/thaw 2 and rain-on-snow climate parameters. These two parameters reflect the increase in warmer winter temperatures and winter rains that are expected to occur in the region of the Willow FSR.

The freeze/thaw 2 climate parameter describes the incidence of frequent freeze-thaw cycling in conjunction with precipitation as rain. The condition can result in water flow onto the roadway and refreezing into an icy sheet that jeopardizes road user safety. This parameter is expected to impact the road prism and all operational consideration categories; and has become a challenge in recent years to the local road users. The forecasted changes in climate are expected to further increase the risks caused by this parameter.

The increase in winter precipitation as rain was determined to also create high-medium risk conditions to ditches, cross drains, and winter maintenance. Local road users expressed concern over the ability of this infrastructure to handle increased wintertime runoff and peak stormflows. This reflects changing climate conditions and a situation in which the infrastructure was not originally designed or maintained to perform as required.

COMPARISON BETWEEN BASELINE AND FUTURE PERIODS

It is important to highlight that the difference in risk scores between future and baseline periods is created by the change in the probability score. Severity scores reflect the assessment of the consequences on the infrastructure of an event occurring. The consequence would remain the same throughout the assessment period; however, the risk may change as the probability of that event occurring may change given the available climate data.

An important change determined by this assessment is that spring thaw will happen, on average, 12 days earlier in the future period (2041-2070), as compared to the baseline period (2011-2040). This means that the duration of winter operations likely will be reduced, which will impact planning and management of forest and mill operations. Log hauling could be subjected to spring weight restrictions earlier in the year, as well.

Risk is not predicted to change for most of the infrastructure and climate interactions in the future. In general, certain climate events may occur more frequently but overall risk levels are predicted to not increase dramatically from the current baseline condition.

STEP 4 – ENGINEERING ANALYSIS

The engineering analysis is an optional step in the PIEVC protocol and has various possible components, including refining the climatic forecasts, and assessing load capacity vulnerability. Those familiar with the design of the infrastructure elements can review the design assumptions, material properties, etc. to assess the anticipated changes in performance given the climate changes anticipated. If design changes are warranted to ensure safety or reliability, then these are recommended.

The assessment 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 responses to climate change on the Willow FSR.

STEP 5 – RECOMMENDATIONS AND CONCLUSIONS

Limitations

Detailed maintenance, inventory, usage, and performance data for the Willow FSR were not available to the assessment team for this analysis. Instead, the assessment team relied almost exclusively on anecdotal accounts from local road users and the local road user maintenance committee to approximate these aspects, and to infer changes in road usage and management in recent years. The information provided by local road users and the road user maintenance committee, therefore, was invaluable for the completion of this assessment.

Climate data was not available for two of the climate parameters considered in the assessment: freeze/thaw 2 and antecedent rain followed by a significant rain event. The assessment team believed that both parameters were important to include in the assessment and, therefore, data for these parameters was generated using professional judgement. The PIEVC protocol provides for this approach if the data gaps and reliance on professional judgement is documented.

Recommendations

The assessment team developed general recommendations concerning the implementation of the PIEVC protocol on resource roads, as well as specific recommendations for the Willow FSR arising from the results of the risk and vulnerability assessment.

GENERAL

The PIEVC process provided a formal, systematic, and comprehensive approach for assessing the vulnerabilities of the Willow FSR's infrastructure to climate-related impacts. The process effectively compiled local knowledge and technical expertise about extreme weather impacts, and projected their future impacts using climate modelling and a risk assessment procedure. More specific recommendations include:

1. It is recommended that the PIEVC process applied to resource roads be further streamlined so that the process focuses on a pre-selected set of key climatic parameters and infrastructure elements & operational considerations. This would allow the workshop participants to focus on assigning vulnerability and severity ratings and understanding the resulting risk scores. As the third case study of the application of the PIEVC protocol on resource roads to occur in B.C., significant improvements in efficiency have been achieved in this regard.
2. It is recommended that a suite of climate packages, including climate parameters and data, suitable for forest management and resource road risk and vulnerability assessments be developed. This would significantly streamline future assessments and would ensure consistency in the application of the anticipated key climate events. This assessment utilized a combination of widely available climdex variables, provided by PCIC, and custom variables that were calculated from various climate data by David Spittlehouse (FLNR climatologist). The derivation of custom variables requires familiarity with manipulating climate data.
3. The application of risk and vulnerability assessments for resource roads may be better suited to road networks in a given area (geographically or administratively defined) rather than to a single, defined, road. This approach has multiple benefits:
    - 3.1. A single climate parameter analysis may apply to all the network roads within the given area.
    - 3.2. A network approach agrees with the generalized management approach normally employed with managed forests and their road access.
    - 3.3. Resource road networks provide access to forest resources, recreational sites, and rural communities. A network-wide assessment of climate impacts allows road owners to proactively and comprehensively consider risks, quantify liability and develop a plan to limit risk, and prioritize expenditures to address vulnerabilities in a manner consistent with corporate and social obligations.
4. The field tour of the road in question proved to be a valuable addition to the assessment process. Exposing the assessment team to critical road infrastructure, failure sites, and road usage needs added to the value and efficiency of discussions during the vulnerability assessment working session held the next day. It is strongly recommended that a field tour by the assessment team be included in any future risk and vulnerability assessments.

5. Also, it is recommended that this assessment be used as a baseline from which general learnings about climate change vulnerability be derived through comparing results with those from other resource road assessments.

WILLOW FSR

The PIEVC protocol directs that recommendations based on the risk and vulnerability assessment be assigned to five major categories:

- Remedial (engineering or operational) actions that are required to upgrade the infrastructure.
- Management actions that are required to account for changes in the infrastructure capacity.
- Continue to monitor performance of the infrastructure and re-assess later.
- No further action required.
- There are gaps in data availability or data quality that need to be addressed.

The vulnerability assessment of the Willow FSR utilized a broad level analysis to the infrastructure along the 92 km length of gravel-surfaced roadway chosen for the case study. The broad level analysis enabled the assessment team to make generalized evaluations of the risks for each of the infrastructure components. This approach, however, is unable to make specific statements regarding site-specific infrastructure or to perform an engineering analysis on a specific infrastructure component or location to determine its resiliency to climate change. Therefore, this case study should be considered as a screening process of potential resource road vulnerabilities rather than specific design recommendations.

The following section presents recommended actions focused on the highly or moderately vulnerable infrastructure arising from the PIEVC assessment of the Willow FSR.

Remedial actions

6. The Willow FSR stakeholders are recommended to initiate the necessary maintenance activities to ensure that the road can perform as operationally required. It was expressed by the assessment team that basic maintenance (grading, roadside brushing etc.) needs improvement to restore drainage, access safety and quality. This improvement will help the infrastructure to achieve resiliency to forecasted weather events and climate change.
7. The condition of soft roads and surface and subgrade failures was identified as the primary concern of the local road users. As a result, the Willow FSR road users must implement practices to reduce this condition and to ensure road resiliency. Practices such as ditch maintenance and improvements, supplemental cross drains, effective grading practices, amongst others must be implemented.

Management actions

8. Further to the need to address the issues related to soft roads and surface and subgrade failures, a cost- benefit analysis of various soft road mitigation measures and technologies such as the use of satellite yards, road friendly vehicles (TPCS), geosynthetic product applications, and proactive road upgrades must be analysed and evaluated for implementation and effectiveness.
9. The Willow FSR road managers and maintenance supervisors, supervisors of industrial operations that use the road, and representatives of the recreational opportunities should review this report and become familiar with the climate change forecasts for the Willow FSR area and how these are likely to impact the performance of vulnerable infrastructure components. They should also read Partington et al., 2017 for an extensive discussion of climate change adaptation measures for resource road infrastructure.
10. A reduction in industrial activities along the Willow FSR has occurred in recent years and is anticipated for the immediate future due to dispersed harvesting to combat a regional infestation of mountain pine bark beetle. Given that a set road maintenance budget must now be allocated amongst many operational roads there is a concern that maintenance activities will continue to be underfunded and that additional climate change-driven risks will remain unaddressed. Road managers should quantify maintenance needs for the Willow FSR, and by extension other key roads in the District, to justify a request for additional funding for road works.
11. A performance inspection protocol should be developed and implemented for all water crossings (major and minor culverts, bridges) and cross drains to ensure these structures are performing as designed. Corrective actions should be taken to restore performance, as needed. Performance inspections will provide site data that can be used to determine future design needs and manage for risks and vulnerabilities to structure performance.
12. A maintenance protocol should be developed and implemented for all water crossings (major and minor culverts, bridges) and cross drains to ensure these structures continue to perform as designed. This protocol should include direction on maintenance frequency, action triggers, and detailed maintenance actions and practices.

Additional study or acquisition of further data

13. The Willow FSR stakeholders should expand efforts to gather and record details about weather events that coincide with peak stream flows and infrastructure failures. Increasing the understanding of how local weather impacts stream flows and infrastructure performance will empower managers, designers, and maintainers to reduce the vulnerability of road infrastructure and control risk associated with local climate changes. Keeping detailed records of climate impacts to Willow FSR infrastructure will allow managers to confirm, refine, or expand this assessment.

14. The Willow FSR stakeholders should implement a process to document road performance details, such as maintenance activities, road usage, and traffic levels, so that this knowledge is retained after experienced staff retire from the workforce. This process also would ensure that maintenance activities and future road designs are optimized by being based on comprehensive and detailed records of road performance. It was communicated to the assessment team that the road user maintenance committee has up-to-date records of major maintenance and repair interventions although it appeared that improvements as outlined would bring further enhancements to the road performance history.
15. It must be ensured that all infrastructure types, especially those that may be considered as minor, such as cross drains and small culverts are included in an inventory and performance database.

REFERENCES

Bradley, A. & Forrester, A. (2018). *Analysis of a British Columbia resource road's vulnerability to climate change – In-SHUCK-ch FSR PIEVC case study*. (Technical report 30). FPInnovations. Pointe Claire, QC.

Engineers Canada. (2016). *PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate, Principles and Guidelines.* (Version PG-10.1).

Nodelman, J. (2017, February). *Tum Tum PIEVC Risk Assessment; a practical introduction to the PIEVC protocol*. Presentation delivered to the Tum Tum FSR PIEVC case study assessment and advisory team.

Partington, M., Bradley, A., Durand-Jézéquel, M., & Forrester, A. (2017). *Adapting resource road infrastructure to climate change*. (Technical Report 61). FPInnovations. Pointe Claire, QC.

Partington, M., Durand-Jezequel, M., & Bradley A. (2018). *Analysis of a British Columbia resource road's vulnerability to climate change – Tum Tum FSR PIEVC case study*. (Technical report 35). FPInnovations. Pointe Claire, QC.

FPInnovations

info@fpinnovations.ca
www.fpinnovations.ca

OUR OFFICES

Pointe-Claire
570 Saint-Jean Blvd.
Pointe-Claire, QC
Canada H9R 3J9
(514) 630-4100

Vancouver
2665 East Mall
Vancouver, BC
Canada V6T 1Z4
(604) 224-3221

Québec
1055 rue du P.E.P.S.
Québec, QC
Canada G1V 4C7
(418) 659-2647