Climate Change Engineering Vulnerability Assessment of Three British Columbia Highway Segments

Highway 20 in the Bella Coola Region

Highway 37A in the Stewart Region

Highway 97 in the Pine Pass Region

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1 Introduction

1.1 Purpose

The BC Ministry of Transportation and Infrastructure (BCMoTI) has engaged in a number of projects to determine risk and vulnerability to transportation infrastructure in BC from future changes in climate. The intent is to understand potential risks to the transportation system and develop adaptation measures to address potential issues. This report details the findings from risk analyses of three highway segments in three different locations in the province. This risk assessment will inform further work in developing advice and guidance on integrating climate change considerations into daily management, planning, engineering, maintenance and operations activities within the Ministry. The results will also help establish guidance in the form of management and standard operating practices, procedures, and the development of technical circulars and scoping documents for government staff and contractors and consultants.

This project benefited from partnering with Natural Resources Canada under their Adaptation Platform intended to advance adaptation to climate change in Canada. BC MoTI has contributed to the Coastal Management theme through the initiative of ***Development of Best Management Practices to Address Extreme Precipitation Events that Affect Coastal Regions of Canada.***

1.2 Background

The specific element of the initiative that this particular report covers is to conduct an engineering vulnerability assessment of three B.C. highway segments:

- Highway 20 in the Bella Coola Region;
- Highway 37A in the Stewart (Bear Pass) Region; and
- Highway 97 in the Pine Pass Region.

The risk identification process that guided BCMoTI through the steps of this vulnerability assessment was ***The PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate*** (Protocol).

Engineers Canada, the business name for the Canadian Council of Professional Engineers, established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee the planning and execution of a broad-based national assessment of the engineering vulnerability of Canadian public infrastructure to changing climatic conditions. One key development of the PIEVC process was the development and application of the Protocol in over 30 applications across Canada and internationally.

BCMoTI previously has executed two vulnerability assessments applying the Protocol:

- Coquihalla Highway between Hope to Merritt; and
- Yellowhead Highway 16 between Vanderhoof and Priestly Hill.

The three highway segments evaluated in this present assessment bring the total number of highway vulnerability assessments conduct in B.C. to five, covering a diverse range of climatic and geographical conditions. Based on the outcomes of the original two assessments, we focused the current work primarily on highway drainage issues arising from extreme precipitation events typified by the conditions that arise from atmospheric river events such as the Pineapple Express.

For the purposes of this study, engineering vulnerability to climate change is defined as the shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure. Vulnerability is a function of:

- Character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed;
- Sensitivities of infrastructure to the changes, in terms of positive or negative consequences of changes in applicable climatic conditions; and
- Built-in capacity of infrastructure to absorb any net negative consequences from the predicted changes in climatic conditions.

Engineering vulnerability assessment requires assessment of all three elements.

The principal method being used to develop a national picture of the engineering vulnerability of infrastructure to climate change is through selective case studies of individual infrastructures or infrastructure systems.

This assessment not only requires a definition, and projection of climatic design parameters, but also the definition of the characteristics and components of the infrastructure, which make them more or less vulnerable to climate change. These can include, but are not limited to:

- Age and condition of the infrastructure;
- Maintenance practices;
- The rate at which system is upgraded or replaced;
- System characteristics;
- Geographical limitations on the system;
- Other factors affecting sustainability of the current system (e.g. population growth);
- The variation in design standards across the country;
- Policies and incentives; and
- Other factors that may be identified.

The five highway segments that have been evaluated comprise a grid that covers the major portions of the B.C. Highway System covering the typical range of geographic and climatic conditions that BCMoTI may encounter in the operation of that system. BCMoTI will draw recommendations and conclusions from this body of work to inform the development of guidance documents and procedures that will enhance the overall resiliency of the Highway System to extreme precipitation events.

1.3 Purpose

The principle objective of this case study was to identify those components of the three highway segments that are at risk of failure, loss of service, damage and/or deterioration from extreme climatic events or significant changes to baseline climate design values.

The assessment was carried out using:

- ***The PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate***, Version VA-10, May 2012 (Publication Pending).

The results of this case study will be incorporated into BCMoTI guidance documents addressing the impact of extreme precipitation events on highway drainage systems. Ultimately, the findings of this assessment and the guidance documents that BCMoTI develops will be used to inform the development of national guidance on addressing the impacts of extreme precipitation on highway systems, typified by atmosphere river precipitation events.

1.4 Study Scope and Timing

The scope of the assessment encompassed the current design, construction, operation and management of this infrastructure as well as planned upgrades or major rehabilitation projects.

We evaluated a range of climate precipitation parameters. The climate analysis included an evaluation of the climate baseline condition based on weather station analysis conducted by the Pacific Climate Impacts Consortium (PCIC) covering the period 1971 through 2000. As well PCIC provided project climate conditions for the period 2041 though 2070, a 28 to 57 year assessment time horizon. PCIC's work included a validation of climate model results against the identified baseline conditions.

The assessment was based on the best information available to the assessment team at the time of the project workshop.

1.5 PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment

The climate change vulnerability assessment followed the Protocol developed by PIEVC. The Protocol provides a framework to define, evaluate, and prioritize information and relationships regarding climate change impacts on the infrastructure.

Findings supported by this framework can be used to support decision-making on future operations, maintenance, planning, and development or potential upgrading or rehabilitation of the infrastructure.

The Protocol outlines five primary steps in the assessment process, as follows:

- Step 1: Project Definition
- Step 2: Data Gathering and Sufficiency
- Step 3: Risk Assessment
- Step 4: Engineering Analysis
- Step 5: Recommendations

In addition, the Protocol provides optional steps to guide organizations through a triple bottom line analysis (TBL) of recommendations arising from vulnerability assessments. TBL analysis would entail a balanced evaluation of the social, environmental and economic factors that may be considered in arriving at fully developed recommendations from vulnerability assessment work.

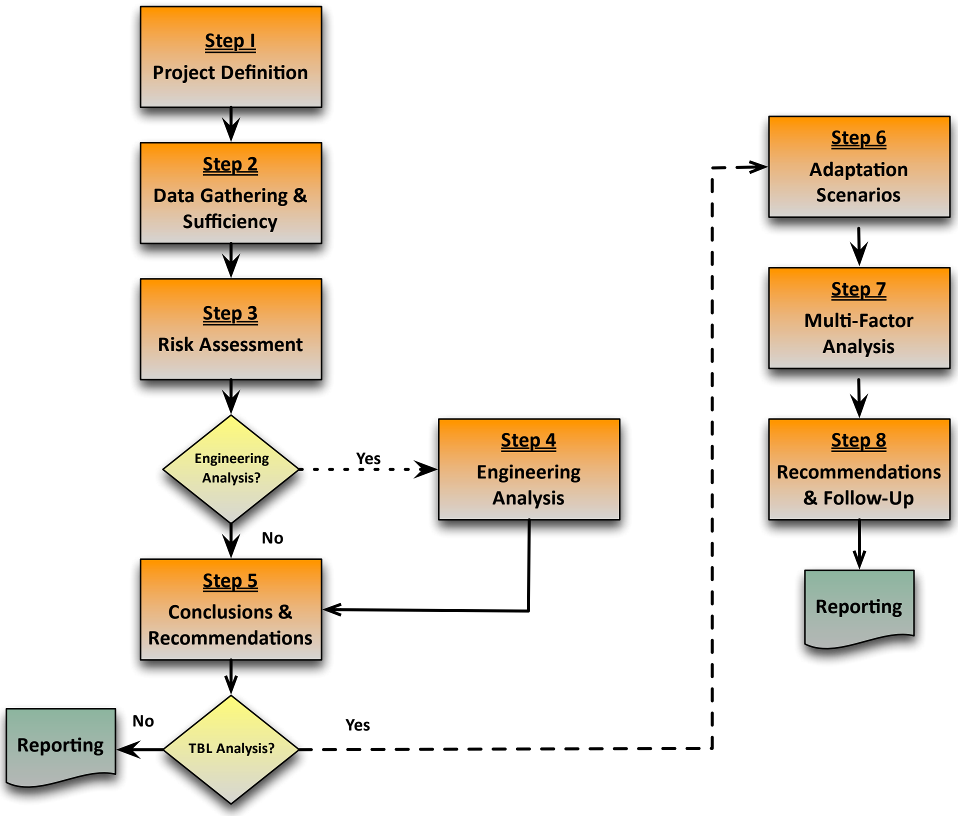
For the purposes of this assessment, we have focused on Steps 1 though 3 and Step 5 of the Protocol. BCMoTI will execute a Step 4, Engineering Analysis with the support of the Nodelcorp team, but this will be reported under separate cover. BCMoT may decide to conduct a TBL analysis of recommendations as an optional step following the completion of this stage of the study.

Each step of the Protocol has an associated worksheet that guides the practitioner through each element of the assessment. We used these worksheets to inform the assessment process and have retained them as supporting documentation (working papers) for the assessment.

This report follows closely the steps outlined in Steps 1 through 5 of the Protocol.

A flowchart outlining the process is presented in **Figure 1.1**. In the following sections we briefly summarize the evaluation process outlined by the Protocol.

Figure 1.1 Process Flowchart for Application of PIEVC Protocol



1.5.1 Step 1 - Project Definition

In this step the evaluation team defines the boundary conditions for the vulnerability assessment.

The team:

- Develops a general description of:
  - The infrastructure;
  - The location;
  - Historic climate;
  - Load;
  - Age;
  - Other relevant factors; and
- Identifies major documents and information sources.

1.5.2 Step 2 - Data Gathering and Sufficiency

In this step the team provides more definition about:

1. Which parts of the infrastructure will be assessed; and
2. The particular climate factors that will be considered.

This step comprises two key activities:

1. Identification of the features of the infrastructure that will be considered in the assessment:

- Physical elements of the infrastructure;
  - Number of physical elements;
  - Location(s);
- Other relevant engineering/technical considerations:
  - Material of construction;
  - Design parameters;
  - Age;
  - Importance within the region;
  - Physical condition;
- Operations and maintenance practices;
- Operation and management of the infrastructure;
  - Insurance considerations;
  - Policies;
  - Guidelines;
  - Regulations; and
  - Legal considerations.

2. Identification of applicable climate information. Sources of climate information include, but are not limited to:

- The National Building Code of Canada, Appendix C, Climate Information;
- Intensity - Duration – Frequency (IDF) curves;
- Flood plain mapping;
- Regionally specific climatic modeling;
- Heat units (i.e. degree-days) (i.e. for agriculture, HVAC, energy use, etc.); and
- Others, as appropriate.

The team is required to exercise professional judgement based on experience and training. This is an interdisciplinary process requiring engineering, climatological, operations, maintenance, and management expertise. The team must ensure that the right combination of expertise is represented either on the assessment team or through consultations with other professionals during the execution of the assessment.

1.5.3 Step 3 - Risk Assessment

In this step the team identifies the interactions between the infrastructure, the climate and other factors that could lead to vulnerability. These include:

- Specific infrastructure components;
- Specific climate change parameter values; and
- Specific performance goals.

The Protocol requires the team to identify which elements of the infrastructure are likely to be sensitive to changes in particular climate parameters. They will be required to evaluate this sensitivity in the context of the performance expectations and other demands that are placed on the infrastructure. Infrastructure performance may be influenced by a variety of factors and the Protocol directs the team to consider the overall environment that encompasses the infrastructure.

Based on these parameters the team performs a risk assessment of the infrastructure's vulnerability to climate change. The interactions identified are evaluated based on the professional judgement of the assessment team. The risk assessment will identify areas of key concern.

The team will identify those interactions that need further evaluation. The assessment process does not require that all interactions be subjected to further assessment. In fact, in the majority of assessments most of the interactions considered will ultimately be eliminated from further consideration. Some interactions may clearly present no, or negligible, risk. Some interactions may clearly indicate a high risk and a need for immediate action. Those interactions that do not yield a clear answer regarding vulnerability may be subjected to the further engineering analysis.

At this stage, the team will also assess data availability and quality. If professional judgment identifies a potential vulnerability that requires data that is not available to the assessment team, the protocol requires that the team revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for risk assessment and/or engineering analysis. The team may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5.

This is a key decision point in the Protocol. The practitioner is required to determine:

- Which interactions require additional assessment;
- Where data refinement is required; and

- Initial recommendations about:
  - New research;
  - Immediate remedial action; or
  - Non-vulnerable infrastructure.

1.5.4 Step 4 - Engineering Analysis

In Step 4 the team conducts focused engineering analysis on the interactions requiring further assessment, as identified in Step 3. BCMoTI, a consultant and Nodelcorp will conduct an engineering analysis involving hydrologic modeling. This will be reported under separate cover.

1.5.5 Step 5 - Recommendations

In Step 5 the team is directed to provide recommendations based on the work completed in Steps 1 through 4. Generally, the recommendations will fall into five major categories:

- Remedial action is required to upgrade the infrastructure;
- Management action is required to account for changes in the infrastructure capacity;
- Continue to monitor performance of infrastructure and re-evaluate at a later time;
- No further action is required; and/or
- There are gaps in data availability or data quality that require further work.

The team may also identify additional conclusions or recommendations regarding the veracity of the assessment, the need for further work or areas that were excluded from the current assessment.

At this stage, the Protocol also requires the team to develop a clear statement regarding the overall vulnerability or resiliency of the infrastructure system to the climate conditions that were considered in the assessment.

1.6 Project Team

Climate change engineering vulnerability assessment is a multidisciplinary process requiring a wide range of engineering, construction, operation, and maintenance skills and knowledge. Furthermore, the team must include deep knowledge of climatic and weather conditions relative to the project location. For this assessment, the primary technical and operations infrastructure knowledge was provided by BCMoTI personnel, who drove the project and were responsible for identifying and assessing the likely response of the infrastructure to projected climate change.

Staff from Pacific Climate Impacts Consortium (PCIC) provided climate change information and projection as well as ongoing advice regarding the interpretation of climatic data.

The membership of the Project Team is outlined in **Table 1.1**.

Table 1.1 BCMoTI Project Team Membership

Area of Responsibility	Team Member
Chief Engineer	Dirk Nyland
Chief Traffic Engineer	Ed Miska
Regional Director	Frank Dacho
Weather Services	Simon Walker
Hydrotechnical	Michael Feduk
Hydrotechnical	Daniel Cossette
Project Manager	Jim Barnes
Regional Manager Engineering	Bill Eisbrenner
Manager Highway Design	Nini Long
Geotechnical	Brent Case
Project Manager	Tony Bennett
Environment	Daryl Nolan
District Manager	Todd Hubner
District Operations Manager	Trent Folk
District Manager	Scott Maxwell
Area Manager	Bryan Crosby
Area Manager	Margaret Henley
District Operations Manager	Dan Palesch
District Manager	Carl Lutz
District Programs Manager	Rosemary Barnewall
PCIC	Trevor Murdock
PCIC	Stephen Sobie

A Project Advisory Committee (PAC) that provided ongoing advice and insight to the project team assisted the project in its work.

The membership of the PAC is outlined in **Table 1.2**.

Table 1.2 Project Advisory Committee

Organization	Team Member
Stantec	Roger Rempel
Risk Sciences International	Heather Auld
Kerr Wood Leidal	Craig Sutherland
Engineers Canada	David Lapp
City of Edmonton	Hugh Donovan
Climate Action Secretariat	Tina Neale
PCIC	Francis Zwiers

BCMoTI retained Nodelcorp Consulting Inc. to facilitate the process and prepare this report.

The membership of the Facilitation and Reporting Team is outlined in **Table 1.3**.

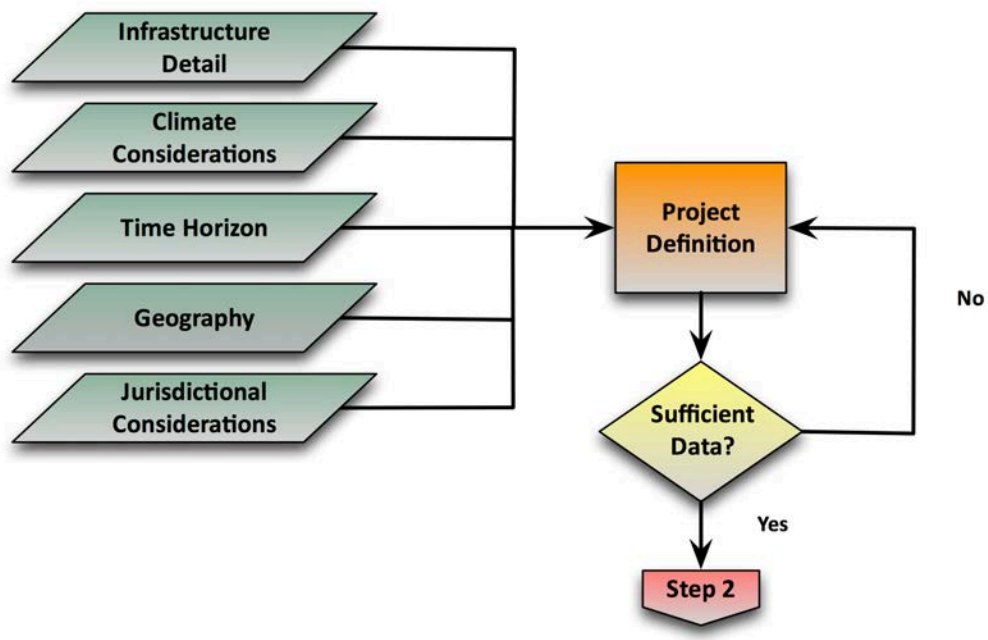
Table 1.3 Facilitation and Reporting Team

Role	Team Member
Facilitation - Reporting	Joel R. Nodelman
Facilitation – Reporting	Joan Y.H. Nodelman

2 Step 1 – Project Definition

The team applied the Protocol process to define the project boundary conditions in space and in time. The process followed the steps identified in the process flowchart presented in **Figure 2.1**.

Figure 2.1 Project Definition Process Flowchart



2.1 Identify Infrastructure

2.1.1 Pre Screening

Our previous work with applying the Protocol on infrastructure systems in BC identified that drainage issues arising from these events are widespread. We observed these phenomena on both previous BC Highway case studies and in other PIEVC studies executed in BC. In all of these case studies, we noted that drainage events related to extreme high rainfall were a common problem experienced by BC infrastructure systems.

In this assessment, BCMoTI evaluated three segments of the BC Highway System:

- Two coastal:
  - Highway 20 in the Bella Coola Region,
  - Highway 37A in the Stewart (Bear Pass) Region; and one interior:

- Highway 97 in the Pine Pass Region.

These highway segments have all experienced significant road-closure events caused by extreme high rainfall related to atmospheric rivers. The intent of this assessment was to directly evaluate these highway segments for infrastructure drainage issues caused by extreme precipitation events such as atmospheric rivers. BCMoTI has direct, hands-on, experience with the impacts of coastal weather systems on these segments. As a result the team was well placed to confirm the information developed by the PCIC climate modeling process. We included the interior Pine Pass segment in this work, as this provided the opportunity to evaluate the wide-ranging impacts of coastal weather and other convective weather systems. With these three new data points and the information gathered through our previous work and by other PIEVC case studies, we will have sufficient information to develop the guidance documents arising from this work.

This application was a targeted assessment applying the Protocol. The work did not contemplate the whole range of issues considered in previous BC Highway vulnerability assessments, as many of these issues were deemed to be low to medium risk, or already have in place management systems to mitigate climate risk. Rather, this work specifically focused on drainage and water management concerns.

The ultimate aim of this work is to identify common risk elements that may be broadly applied to highway infrastructure systems in BC and, ultimately, across Canada. The so-called Pineapple Express events experienced in BC represent a worst-case scenario for atmospheric river-like events that also occur in the Atlantic Provinces and elsewhere in Canada. Atmospheric Rivers are associated with substantial precipitation over short durations that can result in significant damage. Such events have been experienced in almost every jurisdiction in Canada. We plan to use the results from this series of assessment, combined with the results from previous assessments to establish a best practice guidance document for highway infrastructure systems outlining common risk issues and recommended engineering and management processes to mitigate those risks.

2.1.2 Infrastructure Description

We present a map of the five vulnerability assessment locations considered over the previous two vulnerability assessments and this current study in **Figure 2.2**. In **Figures 2.3 (Bella Coola), 2.4 (Stewart) & 2.5** (Pine Pass) we present more detailed maps of the highway segments covered by this assessment. These detailed maps were prepared by PCIC as part of their work on developing climatic parameters for this assessment.

Figure 2.2 Map of Five B.C. Highway Segments Evaluated for Climate Change Engineering Vulnerability

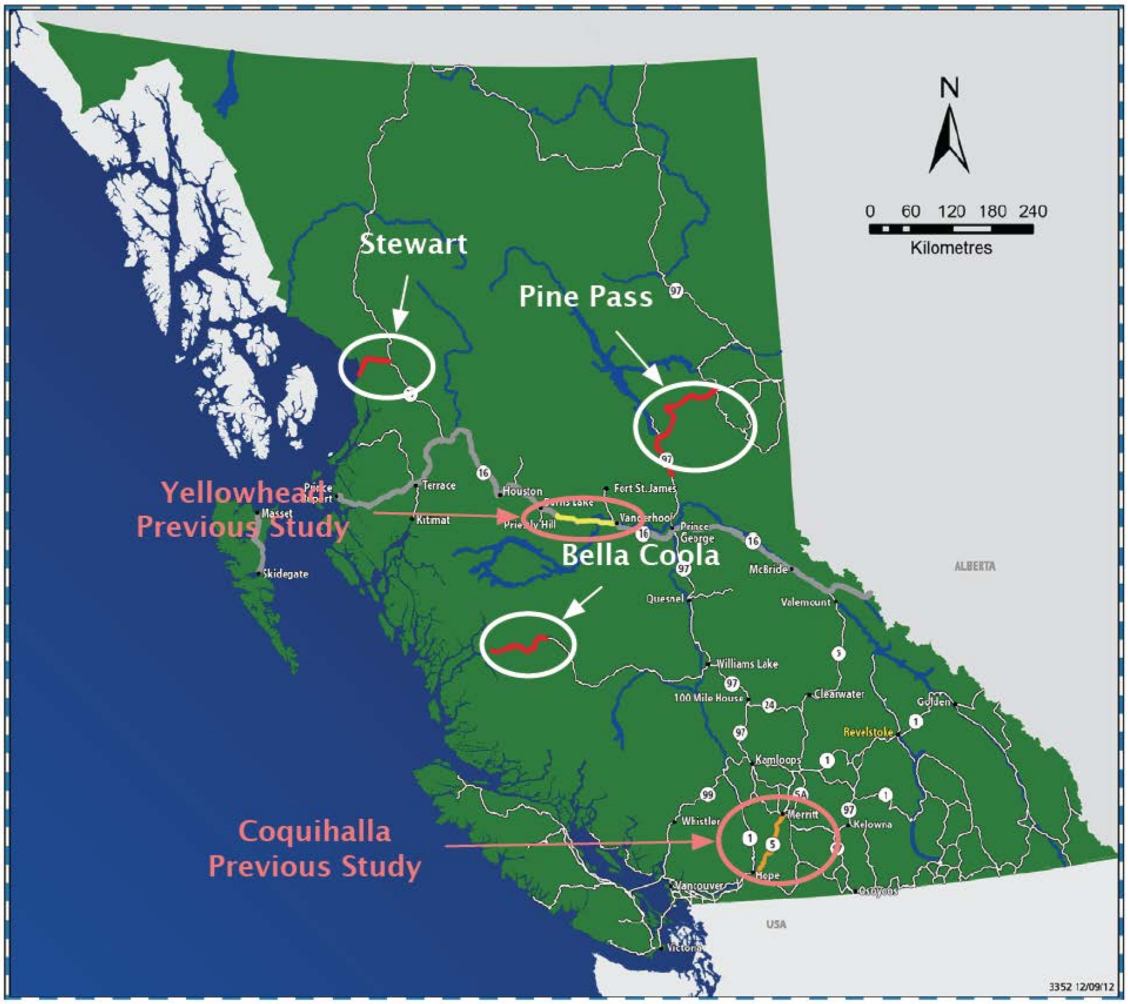


Figure 2.3 Detail Map of the Bella Coola Highway Segment

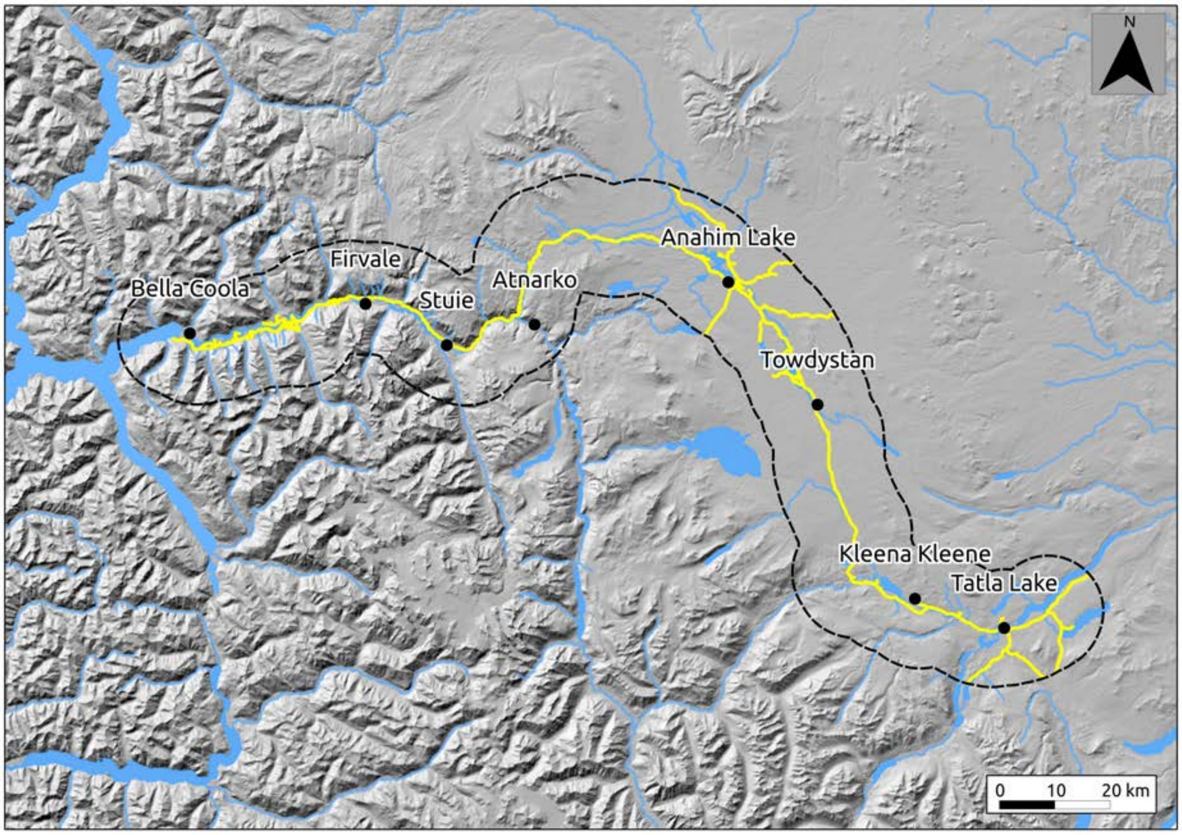


Figure 2.4 Detail Map of Stewart (Bear Pass) Highway Segment

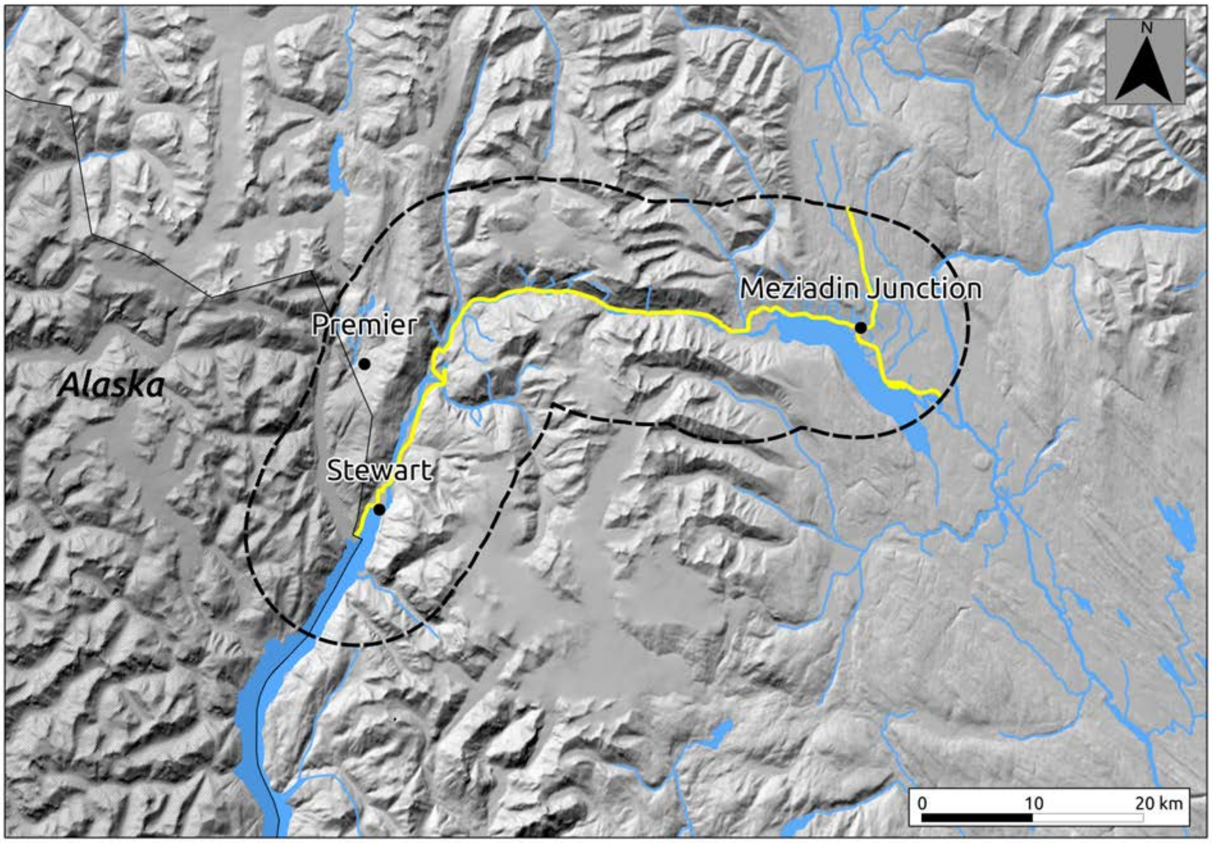
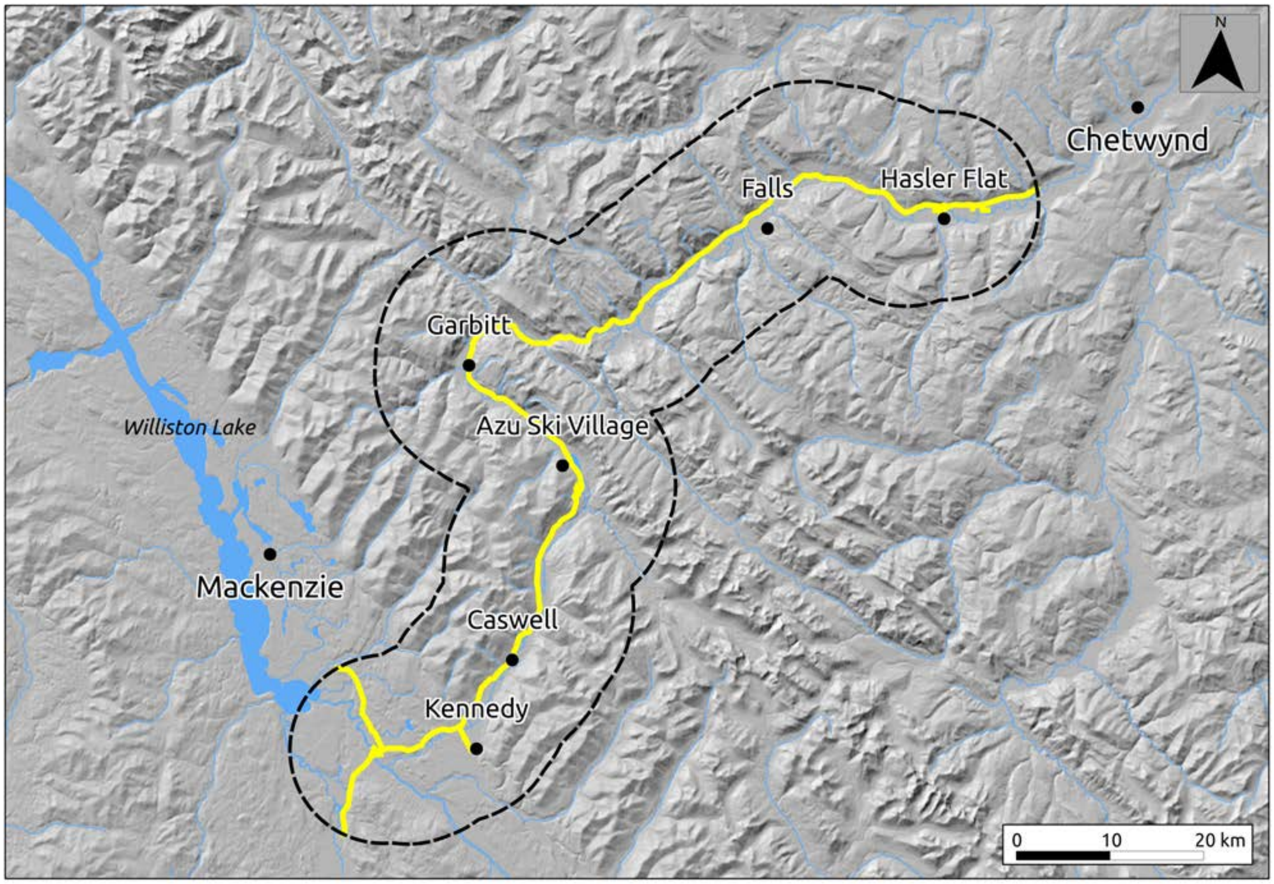


Figure 2.5 Detail Map of the Pine Pass Highway Segment



2.2 Identify Climate Factors of Interest

The identification of climate factors was a recursive process. Initially, the team identified an extensive list of potential climate factors. This initial listing was completed February 27, 2013. As work progressed, the team refined the list of pertinent climate factors based on their understanding of relevant interactions between the climate and the infrastructure. Thus, the list of potential climate factors was adjusted throughout the assessment process ultimately arriving at the list provided in **Table 2.1**.

The same climate parameters and threshold values were applied across all three vulnerability assessments:

- Bella Coola;
- Stewart (Bear Pass); and
- Pine Pass.

This was based on the experience of the team informed through discussions with PCIC.

Table 2.1 Climate Factors Considered in the Vulnerability Assessment

#	Climate Parameter	Infrastructure Indicator	Source/Comments
1	Total Annual Rainfall	407 mm	
2	Extreme High Rainfall	> 98 mm rain	10 year return based derived from ANUSPLIN data from PCIC
3	Light Sustained Rainfall	≥ 5 consecutive days with > 3.5 mm rain	
4	Heavier Sustained Rainfall	≥ 100 mm in 48 hours	
5	Snow (Frequency)	Days with snow fall > 10 cm	
6	Snow Accumulation	5 or more consecutive days with a snow depth > 60 cm	S6-06 Clause 3.1 – Snow loads not normally considered on bridges because a considerable snow load will cause a compensating reduction in traffic load. S6-06 Clause 12.4.1 – consider snow accumulation and snow removal from the deck when considering bridge barrier systems.

Table 2.1 Climate Factors Considered in the Vulnerability Assessment

#	Climate Parameter	Infrastructure Indicator	Source/Comments
			Maintenance Response Standards.
7	Rain on Snow	Period where rain falls on existing snowpack.	S6-06 Clause 1.1.1 – Scope of code – for structures subject to avalanche retain specialists to review and advice. S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider groundwater effects, slope stability, erosion
8	Rain on Frozen Ground	Precipitation > 6 mm/3h No snowfall, Surface Temperature < 0 ^{o}C	
9	Rapid Snow Melt	Snow melt > 9 mm/3h	
10	Snowmelt Driven Peak Flow Events	N/A	Freshet
11	Magnitude of Storm Driven Peak Flow Events	N/A	Includes entire watershed and debris flow.
12	Frequency of Storm Driven Peak Flow Events	N/A	Includes entire watershed and debris flow.
13	Ice / Ice Jams	N/A	Since no direct information, use Probability Scores of 2, 3, & 4

2.3 Atmospheric River (Pineapple Express)

BC experiences unique coastal phenomena that can affect the entire province. The combination of being on the Pacific Rim and multiple large mountain ranges results in climatic conditions that have broad ranging impacts on infrastructure systems and human activity. Pineapple Express is an informal name for an Atmospheric River – a flow of low and mid-level moist air, driven by the subtropical jet stream, that sometimes extends from the region around Hawaii to the west coast of North America[1].

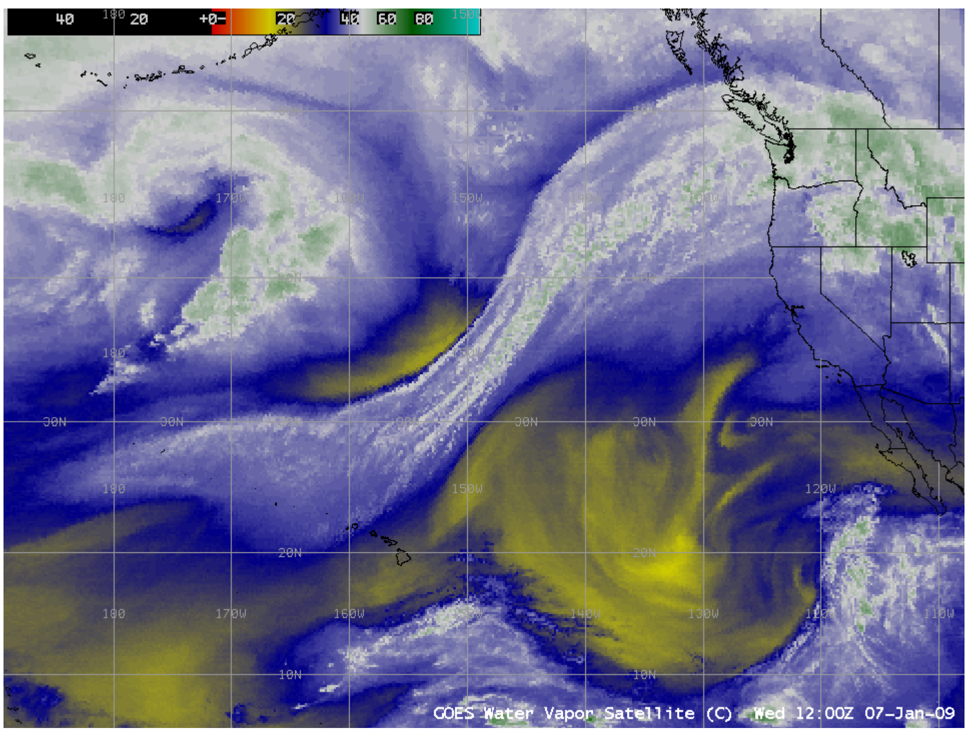
[1] University Corporation for Atmospheric Research (UCAR), http://www.ucar.edu/news/backgrounders/patterns.shtml, Retrieved May 10, 2010

The Atmospheric River or Pineapple Express climate phenomenon results in extreme high rainfall events that occur over very short durations. This causes storm surge impacts on coastal systems but also has far reaching implications for the entire landmass of BC. When these events move inland and interact with mountain ranges the result is extreme weather events that challenge drainage systems across the province and present other challenges for transportation infrastructure.

Figure 2.6 presents a satellite image of a typical Atmospheric River or Pineapple Express event as is often called on the west coast.

The BCMoTI Coquihalla and Yellowhead Highway climate change vulnerability assessments identified that atmospheric river events have increased in both intensity and frequency. The team anticipates that these changes will continue over the time horizon of the study.

Figure 2.6 Atmospheric River Satellite Image (NOAA GOES-11 2009)



2.4 Identify the Time Frame

For the purposes of these assessments the team established a projected time horizon of roughly 60 years. PCIC completed climate forecasts for the period 2041 through 2070. PCIC also established a climate baseline based on meteorological data for the period 1971 through 2000.

2.5 Identify the Geography

As outlined in **Section 2.1**, this assessment focused on three highway segments:

- Two coastal:
  - Highway 20 in the Bella Coola Region,
  - Highway 37A in the Stewart (Bear Pass) Region; and one interior:
- Highway 97 in the Pine Pass Region.

Each highway segment presented unique geomorphological and infrastructural design profiles. BCMoTI staff outlined these unique features, as outlined in **Sections 2.5.1, 2.5.2 and 2.5.3**.

2.5.1 Highway 20 - Bella Coola

Top of Heckman Pass to Bella Coola Warf

This section of highway is approximately 220 km in length. A 200 km length of steep mountain terrain dominates the section, with the majority of the road at the base of the mountain range. There are numerous narrow steep valleys that all feed in to the Bella Coola Valley.

The highway was originally paved in 1979, seal coated in 1994, and patched in a number of areas in 2008. Increased moisture has caused heaving in some sections of the pavement. Approximately twenty industrial loads a day travel in and out of the Bella Coola Valley.

There are approximately 330 culverts from the Top of the Bella Coola Hill to the end of the Highway at Bella Coola Wharf.

The shoulder width in most areas is 2 meters. However there are some sections where the shoulders are much narrower due to differences in the design standard.

The whole section of Highway 20 is ditched.

2.5.2 Highway 37A - Stewart (Bear Pass)

BC/Alaska Border to Meziadin

This 65-km long segment includes:

- Seven km of arterial road from the BC/Alaska Border through Stewart to its eastern edge;
- Roughly 30 km of highway situated along or near the Bear River as it descends from the mountains into the fjord where Stewart is located; and
- 32 km of generally winding mountain road.

Most of the highway's length falls within well-documented avalanche tracks, and winter snowfalls are extreme throughout. Because the highway is squeezed into such a narrow valley, the highway surface is shaded or in the dark for much of the year. The west end of this route is situated in a very wet-freeze environment; the east end is still relatively wet but probably receives half as much precipitation.

Winter temperatures rarely drop below -20 ^{o}C on this stretch of road, but tend to be cooler inland compared to the coast. There are multiple freeze-thaw cycles on this stretch of road in any given year. This stretch of road has a history of water-related damage, particularly during heavy rain events in the fall.

Highway 37A was first paved in the early 1970s:

- The western 17 km (from the border to Bitter Creek Bridge) was last paved in 1992; most of this section (Stewart arterial excepted) was scheduled for preservative sealcoat treatment in 2013.
- The remaining 48 km from Bitter Creek to Meziadin was last paved in 1987 to 1988, but received hot-in-place recycle treatment in 2005, followed by a sealcoat preservation treatment in 2008.

BCMoTI staff estimate pavement thickness to be around 100mm over most of the route. They have very little data regarding the granular structure beneath the pavement. However, based on the road performance, BCMoTI staff concludes that the road has a good, thick granular structure – there are few distortions from frost effects and cracking is of relatively low frequency and severity.

The road exhibits some rutting, particularly towards the inland end on the steep hills. This may be due to heavy loads for resource extraction hauling to the port in Stewart (raw logs and ore concentrate). Extreme freeze-thaw conditions result in the pavement surface being prone to raveling.

2.5.3 Highway 97 - Pine Pass

Highway 97: Parsnip River to Chetwynd

This section of highway is approximately 147km-long running from Pine Pass through the northern Canadian Rockies. The section represents a transition from the milder, wetter interior climate to the colder, drier climate of the prairie, beginning at Chetwynd. There was no road link in this region until the highway was opened in 1953. Paving of the route began in the early 1960s and was complete by 1969. Road gravel structures throughout the 147 km (except for the recently reconstructed sections) are highly variable and poorly documented. Due to the severity of the climate in this area (heavy snowfalls, wet summers, and very cold (to -45 ^{o}C) winters), maintaining a good-quality pavement surface through this stretch is challenging. There are several smaller sub-segments within the 147 km that have distinct histories as outlined below.

1. Parsnip River to Honeymoon Creek Bridge (22 km)

This segment was first paved with 75mm of asphalt in 1962. In 1975, another 150mm of base course and 75mm of pavement was placed over the existing pavement; suggesting that the road strength was inadequate. The pavement was hot-in-place recycled in 1991 without admix, then level coursed and hot-in-place recycled (with 25% admix) again in 2004. The pavement is heavily cracked with a fair amount of distortion due to grade movements from frost. The segment was scheduled for resurfacing in 2013 with a level course/overlay treatment (a total of 62.5mm of new asphalt). At the completion of the 2013 paving program, there will be approximately 150 to 175mm thickness of pavement on the top, with a pavement sandwich layer trapped between 2 base course layers beneath. Given that this segment lasted nearly 40 years without any major paving works (other than the shallow hot-in-place replacement treatments), BCMoTI staff infers that the structure is adequate. The paved width of this segment is just over 8m, with very minimal paved shoulders of 0.3 to 0.5m; this is a standard well below almost all of Hwy 97.

2. Honeymoon Creek Bridge to Ralston Creek (6 km)

This segment has an undocumented early history, but BCMoTI staff infers that it was first paved in the early 1960s along with the rest of the corridor. In the mid-1970s, it was strengthened with cement-treated base (CTB) and repaved. The CTB and asphalt developed extreme cracking and frost heaving and the road surface was in very poor condition (with a very rough ride) from the mid-1980s onward. In 1998, the existing pavement and CTB was reclaimed in place (pulverized), then a filter cloth was placed over the pulverized surface, followed by 150mm of new crushed granular base gravel (WGB), 100mm of asphalt-bound open-graded base, and 100mm of 19mm medium asphalt mix. After 15 years, the pavement has reached the end of its life due to severe transverse cracking, distortion, and raveling. This segment was scheduled for resurfacing in 2013, with a 25mm deep mill, followed by 62.5mm of new pavement placed in 2 lifts.

3. *Ralston Creek to Azouzetta (16.5 km)*

This segment was first paved in 1962 and given a new cement-treated base (CTB) and pavement in the mid-1970s. As in segment 2 above, the CTB did not perform well and this segment developed a terrible ride due to frost heaving of large CTB/pavement slabs each year. In the mid-1990s, the old CTB/pavement was removed and this segment was reconstructed with an entirely new, thick (1m+), free-draining granular structure (OGB) and pavement (150mm ABOGB and 100mm medium mix). Some realignment was carried out during the reconstruction. The pavement surface began to ravel and a preservative sealcoat was placed in 2003; the northern 6 km continued raveling and was hot-in-place recycled (with admix) in 2008. This segment is still characterized by some severe frost heaves and grade movements, probably due to both poor soil conditions (peat and clay) and extreme precipitation – this segment includes the Pine Pass summit at the Powder King ski area where the corridor's heaviest precipitation occurs. The pavement on this segment has reached the end of its lifespan and a hot-in-place recycle or mill/fill treatment is planned for either 2014 or 2015.

4. *Azouzetta to Bennett Creek (15 km)*

This segment was first paved in 1962, but apparently performed very poorly until it was reconstructed in 1983 with a thick, free-draining granular structure and then paved in 1984 with 250mm of pavement (150mm of asphalt-bound open graded base and 100mm of conventional medium mix). Although characterized by high frequency, severe transverse cracking, the segment held up well until the pavement surface was hot-in-place recycled (with admix) in 2004. Nine years later, the severe cracking has returned, along with some raveling and potholes. The segment is scheduled for resurfacing (either HIPR or mill/fill) in either 2014 or 2015.

5. *Bennett Creek to Link Creek (11 km)*

This segment was first paved (with 75mm asphalt) in 1962, was given a pavement overlay twice (100mm in 1980 and 40mm in 1992), and then was reconstructed/widened/realigned (in portions)/paved in 2010 and 2011. During the reconstruction, much of the existing pavement was left in place. Some areas now have close to 300mm of pavement over less-than ideal granular structure. The newer realigned portions have all-new free-draining granular structure with 100mm of new pavement. Because the paving was completed in late October/early November of 2011 under damp, cool conditions, the pavement surface showed signs of raveling the following spring (2012). By 2013, the pavement surface had significantly deteriorated and a preservative sealcoat treatment (or a HIPR) will be required in the next 1-3 years.

6. *Link Creek to West Pine River (7 km)*

This segment was first paved in 1962 (75mm AP), given an overlay (100mm of AP) in 1980, and then reconstructed (and realigned away from avalanche chutes to the opposite side of the valley) in 1993. The reconstruction included placing a thick, free-draining granular layer (OGB) covered with 150mm of asphalt-bound open-graded base and 100mm of conventional medium mix pavement. This segment has held up very well to date. A few rock fills next to the river have settled and distorted at some locations. These are to be repaired this year (2013). The rest of the segment is scheduled for a hot-in-place recycle treatment in 2014 or 2015.

7. *West Pine River to Commotion Creek (54.5 km)*

This segment represents the final push into the dryer, colder climate on the east side of the Rockies, and it experienced the bulk of the damage during the June/July 2011 extreme rainfall event. In it's approximate 60-year history it had never seen such an event, unlike most of the Pine Pass immediately to the southwest, which sees extreme snowfall and run-off events every few years. The south 9.5 km of this segment was first paved in 1964; the remainder wasn't paved until 1969; both portions received 75mm of asphalt initially. The segment was hot-in-place recycled in 1991, then given a 40mm-thick fine mix pavement overlay in 1999. The total pavement thickness should now be around 125mm. The highway's paved surface through this stretch is quite narrow, ranging from 7.4m for the south half (no fog lines) to 7.8m for the north half (fog lines, but barely). Gravel shoulders are also narrow, so this lengthy segment represents perhaps the lowest-standard portion of Highway 97 in the province. Although this segment was severely impacted by the 2011 flood event, both from the damage it incurred and the heavy equipment running on it during the subsequent repairs, the pavement surface fared much better than expected. About 2 to 3 km total of pavement patching remains to be carried out where pavement failures and tracked equipment marks are still present from repair operations. The segment is currently scheduled for resurfacing (likely a hot-in-place recycle treatment) in 2015 or 2016. The pavement surface does show a significant amount of longitudinal cracking due to grade movements from frost action, but other distresses are generally minor.

8. *Commotion Creek to Chetwynd (15 km)*

This segment experienced some minor damage during the 2011 flood event, but held up well. Unlike the previous segment, this one was upgraded to a higher standard (10.3m pavement top width with 100mm of new AP) during a 1986 project (the segment was first paved in 1962 and patched constantly until the 1986 work). In 2007, the segment was again repaved, with a 37.5mm mill/75mm fill asphalt treatment. The total pavement thickness should now be in the 200 to 250mm range. Surface distress consists primarily of longitudinal cracking due to grade movements from frost.

2.6 Identify Jurisdictional Considerations

We identified a long list of potential jurisdictional interests either directly related to the highway segments under consideration and their corridors and also with the regions in general. These interests are identified in **Table 2.2**. These lists evolved from the previous BCMoTI vulnerability assessments.

While maintaining an awareness of these interests and discussing the implications of climate change on the highway in the context of these interests, ultimately the team did not identify a jurisdictional interest that had any incremental affect on the highway when climate change factors were taken into consideration.

During the workshop, the team was primarily concerned about cross-jurisdictional issues primarily related to railway infrastructure and pipelines. These interests were discussed extensively during the two-day risk assessment workshop. However, ultimately the team did not identify a jurisdictional consideration that was materially affected by climate change.

Table 2.2 Jurisdictional Considerations

Jurisdiction	Consideration
Department of Fisheries and Oceans	*Fisheries Act* requirements will influence the design of replacement structures on fish streams.
Ministry of Environment	▪ Wildlife and Vegetation ▪ Fish habitat ▪ Water Act Approvals ▪ Biodiversity protection (e.g. fish, vegetation, wildlife, habitat) ▪ Water Act approvals (e.g. diversions, withdrawals) ▪ Pollution prevention (e.g. spills, contaminated runoff) ▪ Parks and protected areas ▪ Provincial Park at Falls Lake ▪ Etc.
Rail	May have some influence on maintenance and refurbishment
First Nations	There are a number of First Nations within the vulnerability assessment study areas, as follows: Bella Coola • Nuxalk Nation Stewart

Table 2.2 Jurisdictional Considerations

Jurisdiction	Consideration
	• Nisga Nation Bear Pass • McLeod Lake Indian Band • West Moberly First Nations • Halfway River First Nation • Saulteau First Nations
Ministry of Forests	Forest road access may be a concern
Transport Canada	*Navigable Waters Protection Act* requirements will influence the design of replacement structures.
Industry Canada	Regulates Radio and Electronics as well as Explosive use
Pipelines (NEB) Natural gas etc.	May have some influence on maintenance and refurbishment
Power Transmission Lines	May have some influence on maintenance and refurbishment
Provincial Ministry of Environment Parks & Recreation	▪ BC Wildlife Act ▪ BC Water Act

2.7 Site Visit

The team did not deem it necessary to conduct a site visit for this assessment.

The team comprised BCMoTI staff with significant hands-on experience in the design, operation, and maintenance of this highway. Thus, during the workshops the team had a deep foundation of skills and experience to draw from in assessing the impact of climate change on the infrastructure.

2.8 Assess Data Sufficiency

Upon completion of Step 1 of the Protocol, the team determined that they had sufficient data to proceed to Step 2 of the assessment.

In general, the experience of the team compensated for any lack of specific design data.

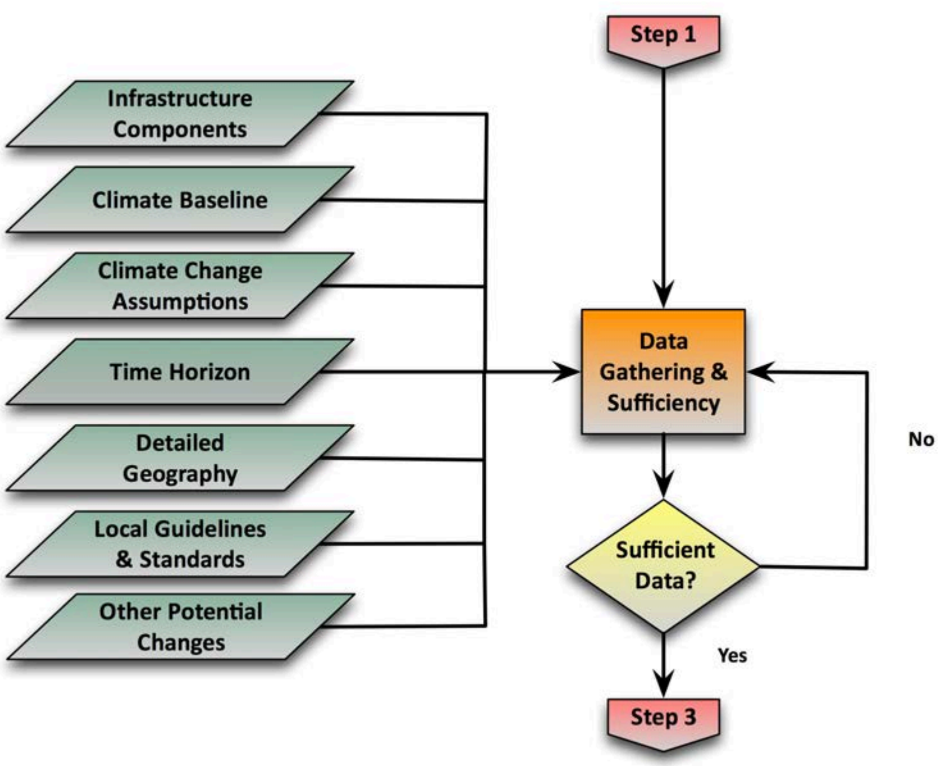
In retrospect, the team was correct in stating that there is sufficient data to actually assess the risk of climate change on infrastructure and accommodate most of the data gaps through experience and local knowledge.

3 Step 2 – Data Gathering and Sufficiency

The Protocol applies a recursive process to identify, locate and define data used in the risk assessment process. In Step 1, the Protocol establishes the project boundary conditions. In Step 2, these definitions are further refined to provide an in-depth definition of the climate parameters and specific infrastructure sub-components to be considered in the risk assessment. This is accomplished through a detailed review of the specific characteristics of the infrastructure and its sub-components. Infrastructure components are the physical, operational and procedural features of the infrastructure that the team defines to be potentially vulnerable to climate change. Throughout the remainder of the assessment process, these components are reviewed, refined and assessed to determine the specific level of vulnerability. It is quite common that the process identifies no vulnerability for a large number of components. This is a positive outcome since it represents a focussed review of the situation and an active decision regarding vulnerability.

The process followed the steps identified in the process flowchart presented in **Figure 3.1**.

Figure 3.1 Step 2 – Data Gathering and Sufficiency Process Flowchart



Initially, lists were compiled based on the work completed during the previous two BCMoTI vulnerability assessments. These were further refined at the Workshop in August 2013.

3.1 State Infrastructure Components

The team spent considerable effort to define relevant infrastructure components for three highway segments. As noted above, the team continuously refined this list throughout the process and finalized the list at the risk assessment workshop in August 2013.

The team reviewed each component of the infrastructure and considered its vulnerability from a number of perspectives, based on the experience and skills represented by the team membership. This allowed the team to conduct a thorough review and ensured that, at the risk assessment workshop, there was a common understanding of the infrastructure characteristics being contemplated in the assessment.

The final infrastructure component listings for the three highway segments are presented in **Tables 3.1, 3.2 and 3.3.** For the purposes of consistency across the three highway segment assessments, we maintained the same base infrastructure list and numbering scheme. During the workshop, the team reviewed the lists and identified those infrastructure components that were relevant to the assessment and those that were not. The three highway segments are located in three distinctly different geomorphological regions and were constructed over different time frames. Consequently, the three highway segments do not have identical infrastructure component configurations. Where items identified on the list are not present on a particular highway segment, the team identified these components as not applicable and removed them from further consideration. In **Tables 3.1, 3.2, and 3.3** these decisions are identified and that line of the table is greyed out.

Table 3.1 Infrastructure Component Listing – Bella Coola

#	Infrastructure Components
#	**Infrastructure**
	Above Ground
1	Shoulders (Including Gravel)
2	Curb (N/A)
3	Ditches
4	Embankments / Cuts
5	Natural Hillside/Slope Stability
6	Protection Works / Armouring
7	Engineered Stabilization Works
8	Structures that Cross Streams
9	Retaining Walls (N/A)
	Below Ground
10	Road Sub-Base
11	Detail Drainage (N/A)
12	Drainage Appliances (N/A)
13	Sub Drains (N/A)
14	Catch Basins (N/A)
15	Grates (N/A)
16	Culverts < 3 meters
17	Culverts >3 meters
18	Bridge End Fill

Table 3.2 Infrastructure Component Listing – Stewart (Bear Pass)

#	Infrastructure Components
#	**Infrastructure**
	Above Ground
1	Shoulders (Including Gravel)
2	Curb (N/A)
3	Ditches

Table 3.2 Infrastructure Component Listing – Stewart (Bear Pass)

Infrastructure Components	
4	Embankments / Cuts
5	Natural Hillside/Slope Stability
6	Protection Works / Armouring
7	Engineered Stabilization Works
8	Structures that Cross Streams
9	Retaining Walls
Below Ground	
10	Road Sub-Base
11	Detail Drainage (N/A)
12	Drainage Appliances (N/A)
13	Sub Drains (N/A)
14	Catch Basins (N/A)
15	Grates (N/A)
16	Culverts < 3 meters
17	Culverts >3 meters
18	Bridge End Fill

Table 3.3 Infrastructure Component Listing – Pine Pass

Infrastructure Components	
#	**Infrastructure**
Above Ground	
1	Shoulders (Including Gravel)
2	Curb
3	Ditches
4	Embankments / Cuts
5	Natural Hillside/Slope Stability
6	Protection Works / Armouring
7	Engineered Stabilization Works
8	Structures that Cross Streams

Table 3.3 Infrastructure Component Listing – Pine Pass

	Infrastructure Components
9	Retaining Walls
	Below Ground
10	Road Sub-Base
11	Detail Drainage (N/A)
12	Drainage Appliances - Spillway
13	Sub Drains (N/A)
14	Catch Basins
15	Grates (N/A)
16	Culverts < 3 meters
17	Culverts >3 meters
18	Bridge End Fill

3.2 Detailed Climate Considerations

3.2.1 PCIC Climate Baseline Analysis and Climate Change Projections

The Pacific Climate Impacts Consortium (PCIC) prepared detailed climatic analysis in support of this assessment. They have provided a report of their work under separate cover. For the purposes of this report, we summarize the outputs from the PCIC analysis as applied within the context of the risk assessment process.

PCIC's work was based on the application of detailed climatic models and regional downscaling. They considered both the historic climate and projected future climatic conditions. For the historic climate, the PCIC analysis considered both the meteorological record and the ability of the modelling process to align with that historic record. This "ground truthing" or validation instilled confidence in the team to apply the same modelling approaches to future climatic conditions. However, that being stated, there were a number of situations where climate modelling approaches could not be used to establish parameters for this assessment. Where this occurred, the team assigned climatic probability values based on:

- A synoptic process based on professional judgement; or
- Arbitrarily assigning climate change probabilities for specific parameters and then adjusting those probabilities using sensitivity analysis to determine the impact on risk outcomes.

All of these approaches are sanctioned by the Protocol.

In the following sections we summarize the climatic data used for this assessment. There were three different climatic regions considered:

- Bella Coola;
- Stewart (Bear Pass); and
- Pine Pass.

Each of these regions is discussed separately in **Sections 3.3, 3.4 and 3.5**.

For the climate baseline work, PCIC accessed ANUSPLIN, a database that includes climate data for all of Canada from 1951-2005 and has been processed so that the data provides uniform coverage for all of Canada. ANUSPLIN provides a gridded observational dataset that is based on weather station records. The individual station records are interpolated to fill in missing areas and in order to create a uniformly gridded dataset across Canada. In this work ANUSPLIN was used for:

- Comparison to model output for validation purposes; and
- For model calibration.

3.2.2 Climate Modeling Uncertainties

Climate modeling is based on inherent assumptions regarding various CO_2 emissions scenarios. Additionally, there is a significant level of statistical uncertainty associated with both the modeling and the analytical approaches used to downscale information generated by regional climate models to local conditions. PCIC addressed this concern by correlating model projections with observed, baseline, climate conditions.

Socio-economic scenarios drive CO_2 emissions that both RCMs and GCMs require as input to produce climate projections. There are uncertainties associated with the estimates of future population and energy use that underpin these scenarios. The process of downscaling climate projections to local conditions introduces additional uncertainty. PCIC addressed this issue by providing output from a cohort of models. Since, there may be a relatively high degree of uncertainty associated with the imbedded assumptions, there can be a high level of uncertainty associated with the model outputs.

Climate models are based on the fundamental equations of motion, and make use of the best available representations of the climate system (including the atmosphere, ocean, land, cryosphere, and biogeochemical phenomena) to produce simulations of the Earth's climate. However, these models rely on inputs and processes with varying degrees of uncertainty that contribute to the resulting model simulations. Additionally, the climate system experiences natural variability (e.g. El Nino, La Nina, Pacific Decadal Oscillation) on scales of days to centuries which adds uncertainty that cannot be eliminated from modeling results.

To compensate for this uncertainty, where possible, PCIC ground-tested the data by correlating model outputs with observed meteorological data. Nonetheless, users of climate model data must routinely address a range of model outputs and confidence intervals. This is normally achieved through testing the model output against local knowledge and broader synoptic analysis.

3.2.3 Sensitivity Analysis

Sensitivity analysis is subjective. Probability scores are assigned arbitrarily and then tested by adjusting the scores. The results are also rationalized through the skills and experience of the assessment team. Sensitivity analysis is not the best approach for assessing risk. However, it does allow the team to screen risks and determine where more detailed study may be necessary.

Since sensitivity analysis is subjective, it is important to test the assumptions by increasing the scoring to generate higher risk outcomes from the assessment. Once this is done, the team can assess the impact of the probability scoring and make rational recommendations regarding the need for additional work to further resolve these climate parameters.

3.3 Bella Coola

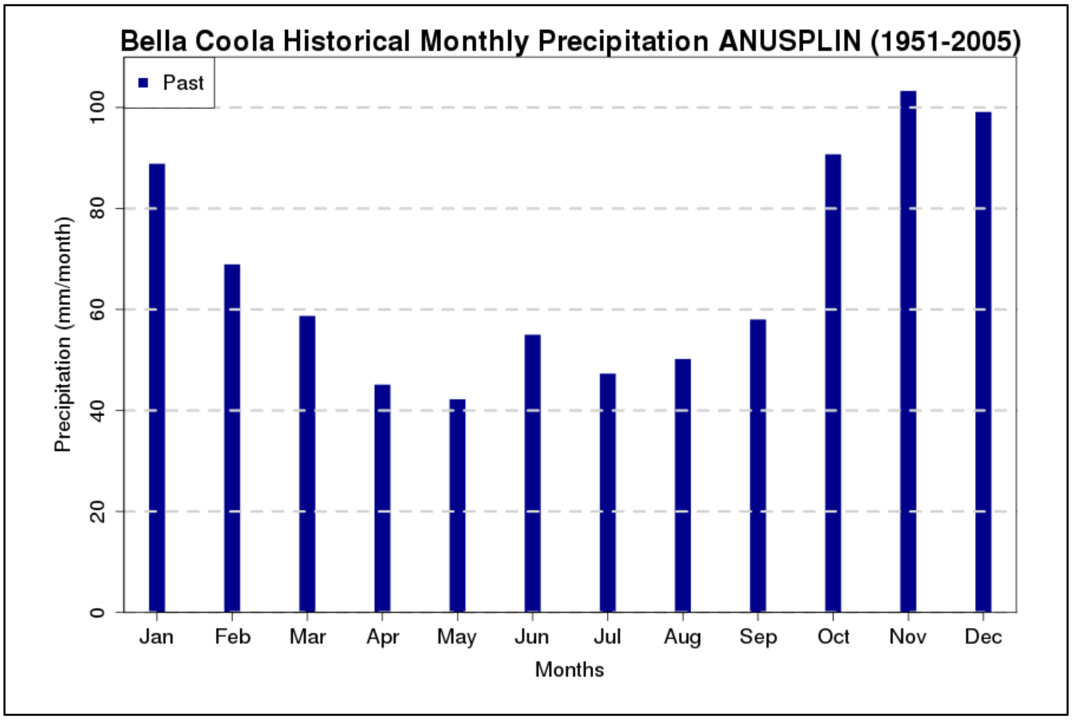
3.3.1 Climate Baseline

Bella Coola and Bear Pass have similar climates, both being highly influenced by coastal features. Winter storms dominate the precipitation record in the winter. In the Bella Coola Region, the long stretch of highway spans two different climate regimes. The western half in the mountains is influenced by coastal affects, while the eastern half is more interior or continental climate. As a result, the metrological record captures two different effects.

In **Figure 3.2** we present the historic average monthly precipitation values for the Bella Coola Region and a detailed map of historic precipitation values for the region.

In **Table 3.4** we present a set of climatic indicators for the Bella Coola region based on the ANUSPLIN historic record for the region. In this table we present two sets of indicators, one for the region and one for the gridded observations from the ANUSPLIN database. The station values tend to be a bit more extreme, as they represent results from one specific location. The regional values represent are somewhat attenuated by averaging across a number of grid cells within the region. As snowfall is not available from ANUSPLIN or from the downscaled model output directly, we have created a snow proxy instead. This is simply the total precipitation that falls during days when the minimum temperature is below zero.

Figure 3.2 Historic Monthly Average Precipitation in the Bella Coola Region



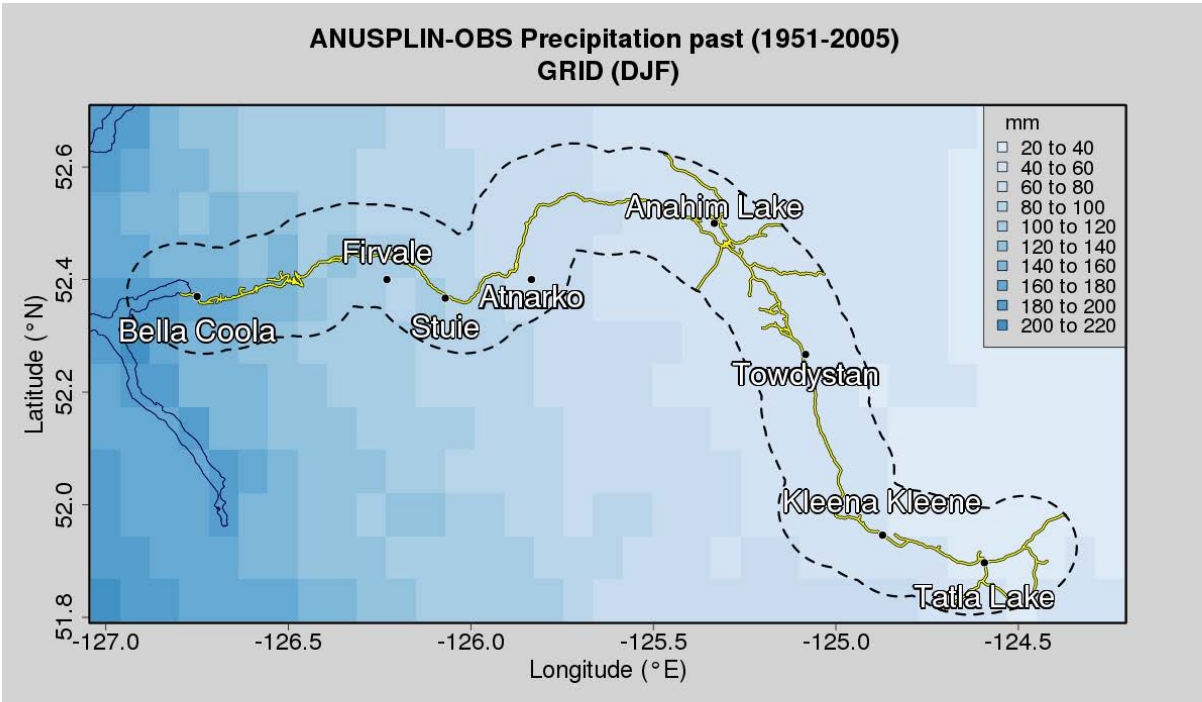


Table 3.4 Historic Bella Coola Climate Indicators

Precipitation	Value
Station Indicators	
Annual Total	1,456 mm/year
10-Year Return Period	105 mm/24hr
25-Year Return Period	127 mm/24hr
Snow Proxy	14 events/year
Regional Indicators	
Annual Total	673 mm/year
10-Year Return Period	36 mm/24hr
Snow Proxy	6 events/year

3.3.2 Future Climate

For the Bella Coola region, PCIC projects increases in precipitation throughout most of the year. The increases are greatest during the winter months and smallest during the summer months.

In the summer months, the northern most section of the Bella Coola region is projected to see a small increase, while the rest either stays the same or decreases slightly.

We present the changes in precipitation indicators in **Table 3.5**. In **Figure 3.3** we present the monthly change in precipitation and in **Figures 3.4 and 3.5** we present the projected changes in precipitation for the summer and winter periods.

Table 3.5 Projected Changes in Precipitation – Bella Coola Region

Indicator	Past (1971-2000)	Future (2041-2070)	% Change
Annual Total (mm)	673	744	11
10-year Return Event (mm/24hr)	36	47	31
25-year Return Event (mm/24hr)	44	60	36
5-Day Precipitation (mm)	56	67	20

Figure 3.3 Projected Monthly Precipitation – Bella Coola

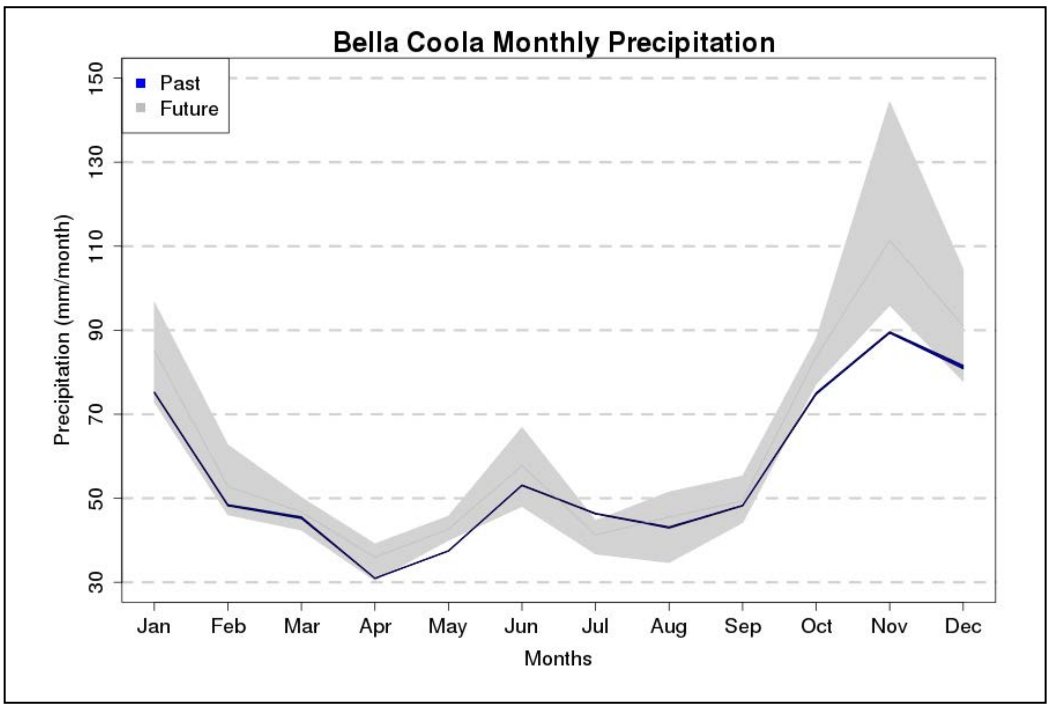


Figure 3.4 Projected % Change in Precipitation – Winter – Bella Coola

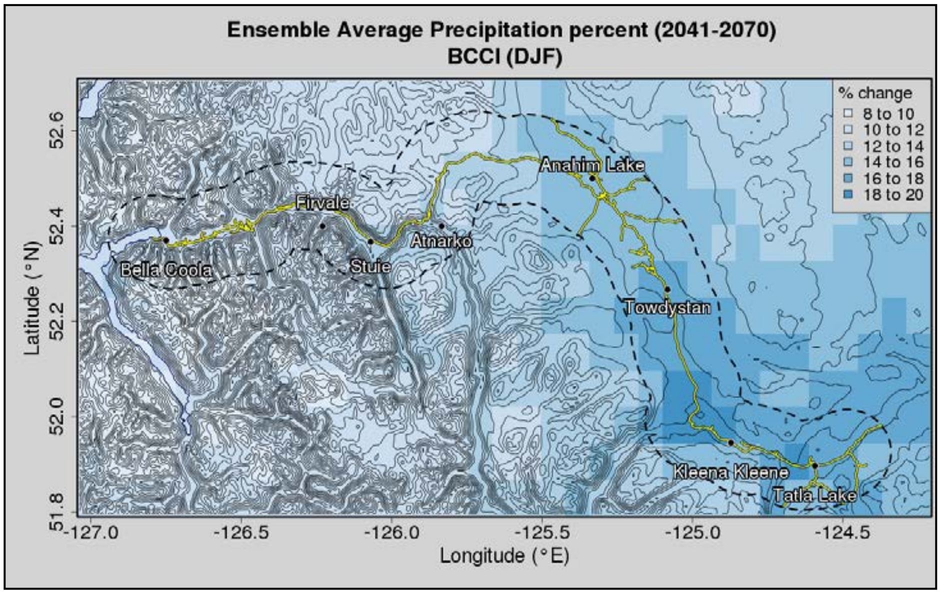
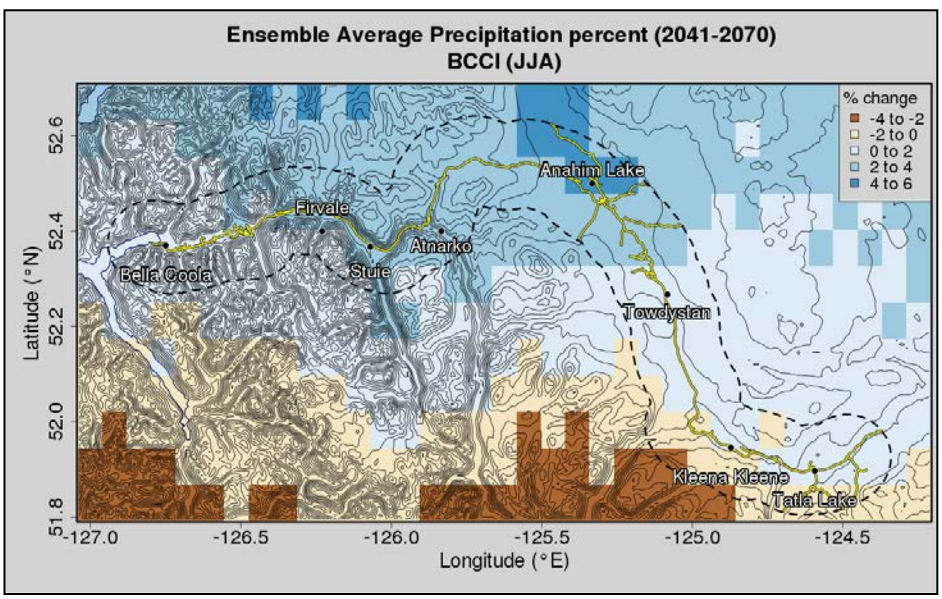


Figure 3.5 Projected % Change in Precipitation – Summer – Bella Coola



3.4 *Stewart (Bear Pass)*

3.4.1 Climate Baseline

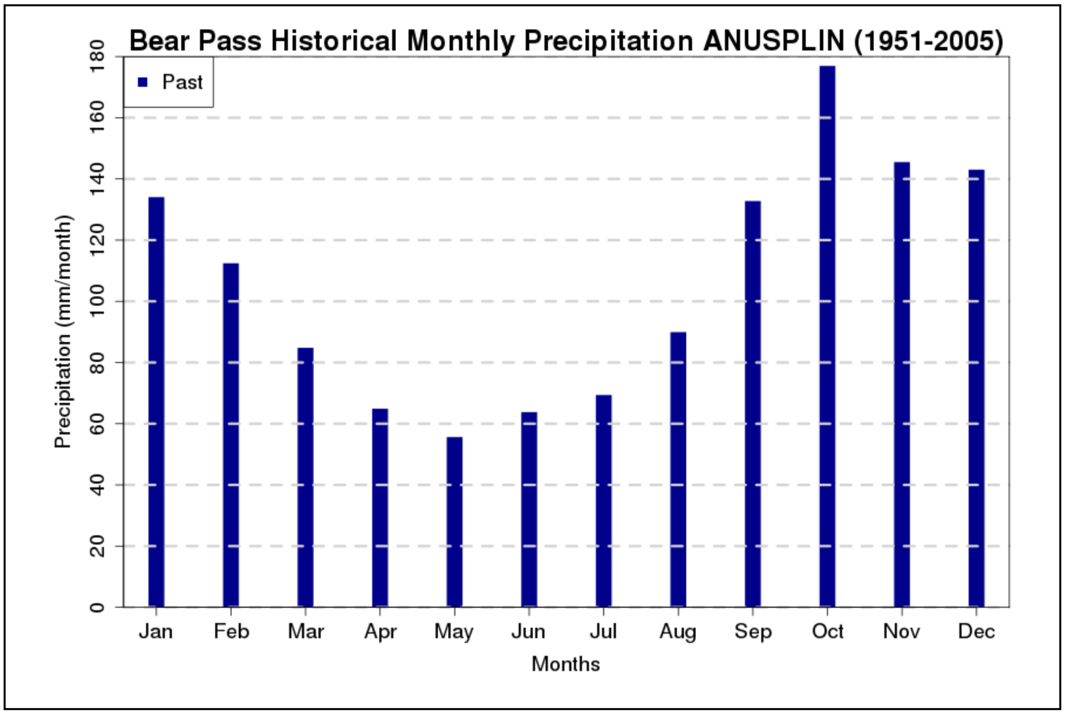
Bear Pass is the rainiest of the three regions considered in this assessment, due to its coastal location and being further north. The region exhibits has a strong seasonal cycle to its monthly precipitation that reflects the changing circulation off the coast and the large storms that primarily occur during the winter.

Precipitation is relatively uniform along the highway, though the Stewart end does receive more precipitation on average than the rest of the region during the winter months.

In **Figure 3.6** we present the historic average monthly precipitation values for the Stewart Region and a detailed map of historic precipitation values for the region.

In **Table 3.6** we present a set of climatic indicators for the Stewart region based on the ANUSPLIN historic record for the region. In this table we present two sets of indicators, one for the region and one for the gridded observations from the ANUSPLIN database. The station values tend to be a bit more extreme, as they represent results from one specific location. The regional values represent are somewhat attenuated by averaging across a number of grid cells within the region. As snowfall is not available from ANUSPLIN or from the downscaled model output directly, we have created a snow proxy instead. This is simply the total precipitation that falls during days when the minimum temperature is below zero.

Figure 3.6 Historic Monthly Average Precipitation in the Stewart (Bear Pass) Region



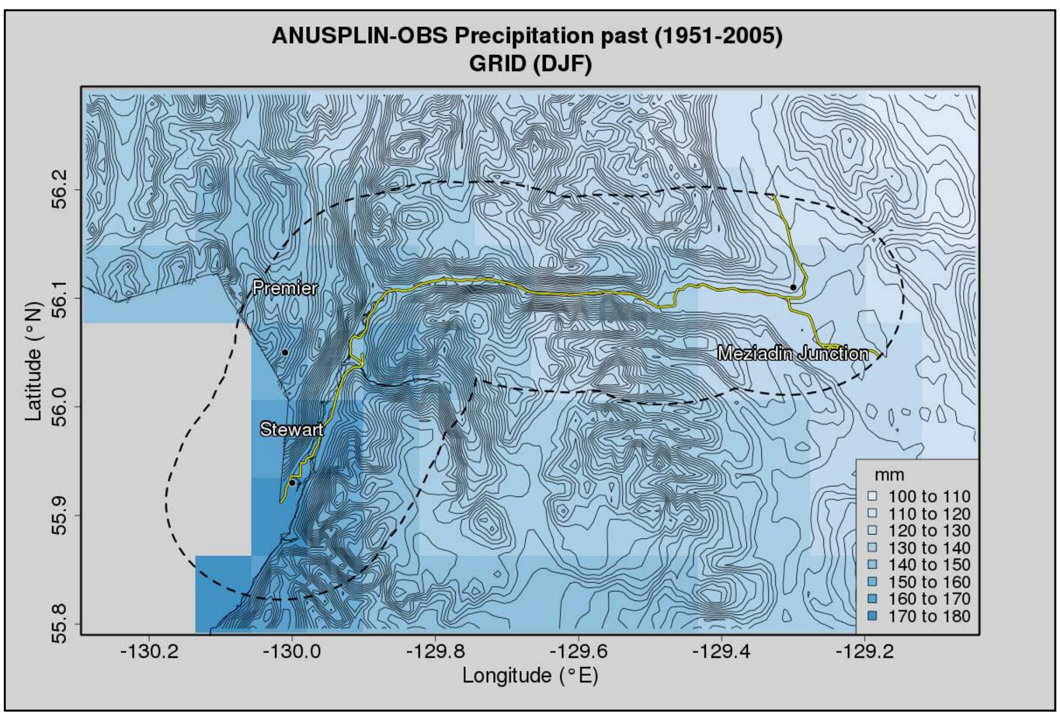


Table 3.6 Historic Bella Coola Climate Indicators

Precipitation	Value
Station Indicators	
Annual Total	1,802 mm/year
10-Year Return Period	103 mm/24hr
25-Year Return Period	116 mm/24hr
Snow Proxy	15 events/year
Regional Indicators	
Annual Total	1,290 mm/year
10-Year Return Period	64 mm/24hr
Snow Proxy	18 events/year

3.4.2 Future Climate

In the Stewart (Bear Pass) region, PCIC is projecting increases in precipitation in all months with the largest increases occurring during the winter months. Those increases are distributed pretty uniformly throughout the region in both winter and summer, though the summer changes are fairly negligible.

PCIC also projects corresponding increases in the precipitation indicators for the region with 14% increase projected for the annual total precipitation. Larger changes are projected for the more extreme events.

We present the changes in precipitation indicators in **Table 3.7**. In **Figure 3.7** we present the monthly change in precipitation and in **Figures 3.8 and 3.9** we present the projected changes in precipitation for the summer and winter periods.

Table 3.7 Projected Changes in Precipitation – Stewart (Bear Pass) Region

Indicator	Past (1971-2000)	Future (2041-2070)	% Change
Annual Total (mm)	1290	1477	14
10-year Return Event (mm/24hr)	64	80	25
25-year Return Event (mm/24hr)	75	96	28
5-Day Precipitation (mm)	96	120	25

Figure 3.7 Projected Monthly Precipitation – Stewart (Bear Pass)

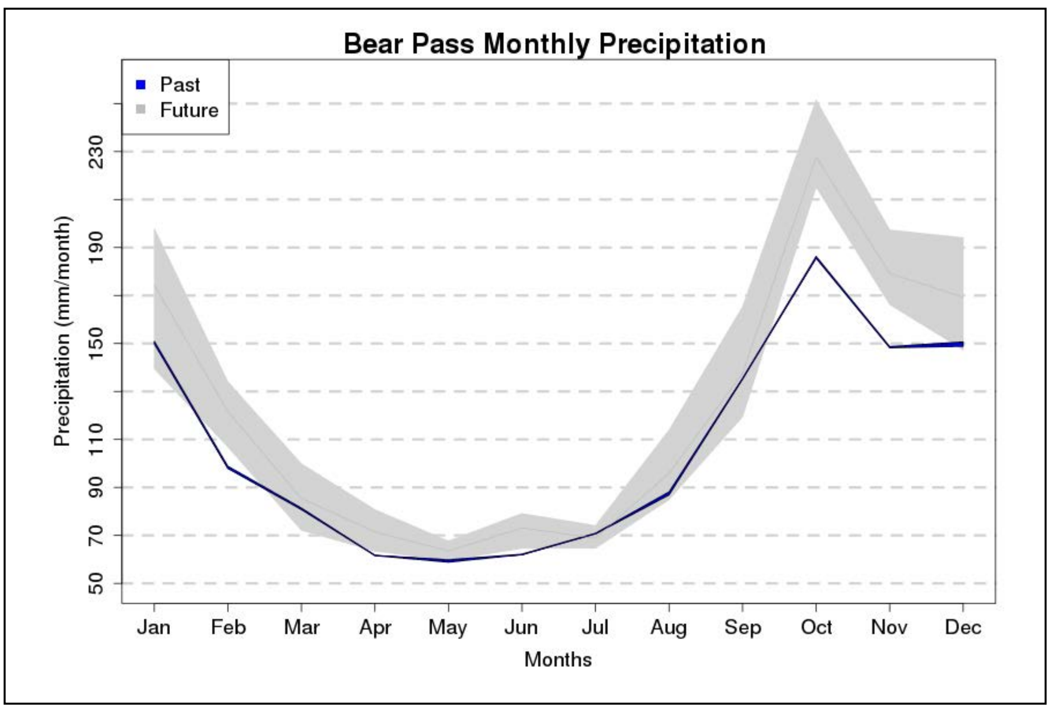


Figure 3.8 Projected % Change in Precipitation – Winter – Stewart (Bear Pass)

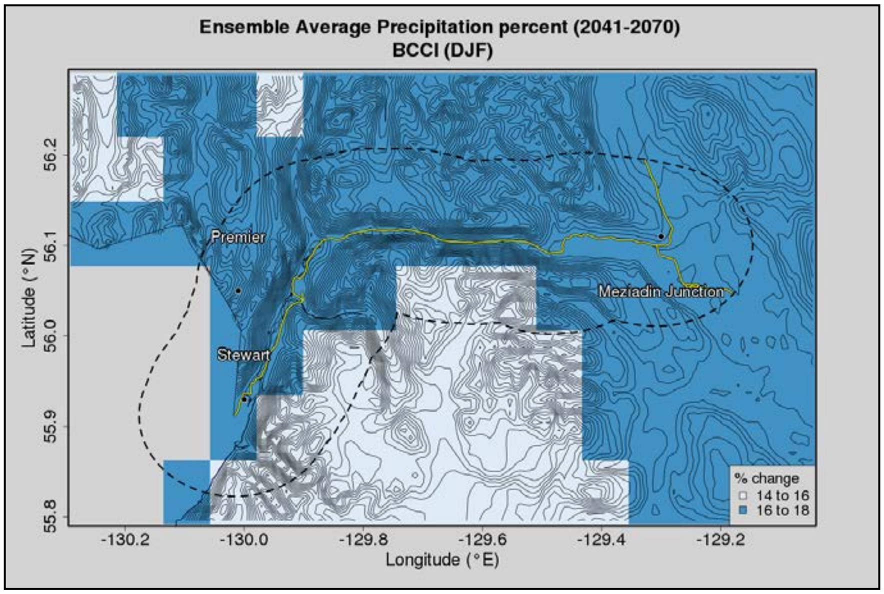
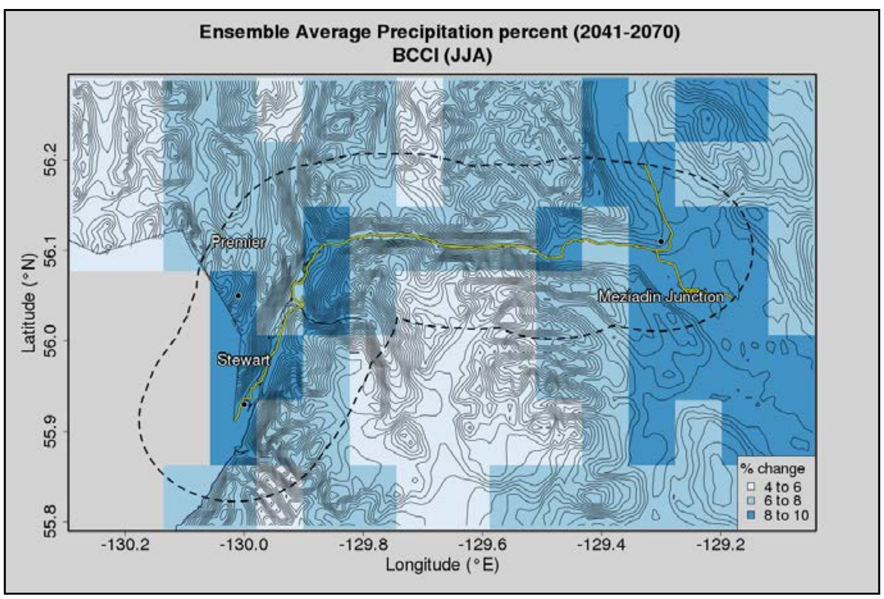


Figure 3.9 Projected % Change in Precipitation – Summer – Stewart (Bear Pass)



3.5 *Pine Pass*

3.5.1 Climate Baseline

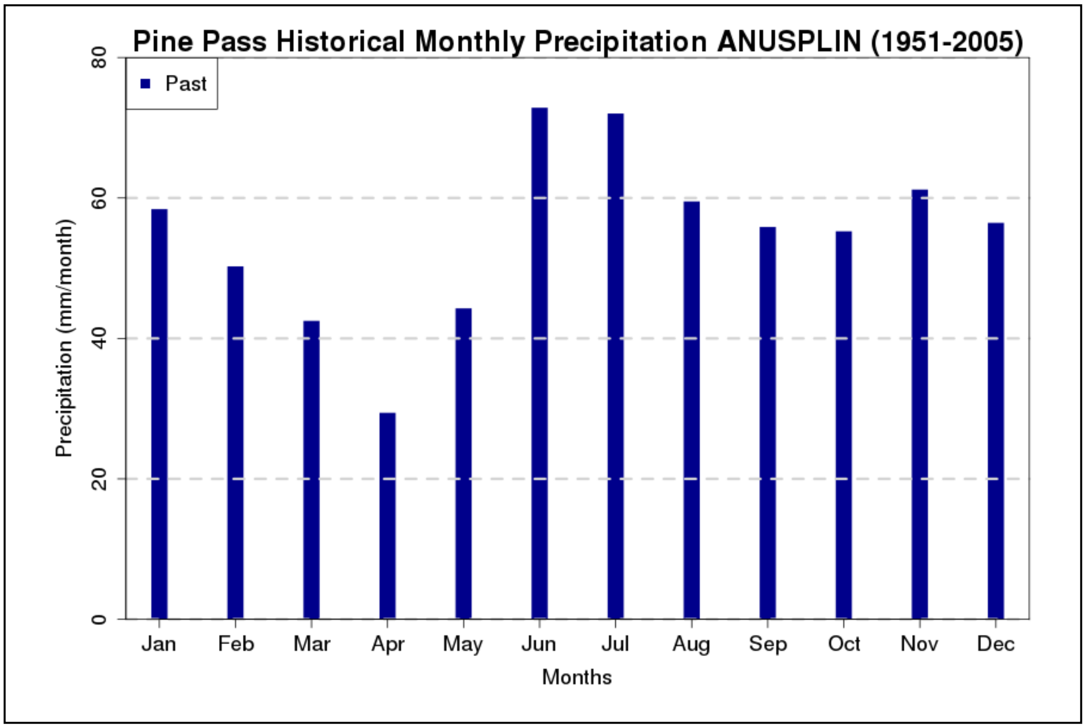
Pine Pass is somewhat different than the other two regions. It is further inland and much less affected by oceanic storms. The region and is more influenced by summer convective events.

The summer months receive the most precipitation, which falls mostly in the mountains of the pass. In this region, precipitation is fairly uniform except for the southern end of the pass, approaching Mackenzie.

In **Figure 3.10** we present the historic average monthly precipitation values for the Pine Pass Region and a detailed map of historic precipitation values for the region.

In **Table 3.8** we present a set of climatic indicators for the Pine Pass region based on the ANUSPLIN historic record for the region. In this table we present two sets of indicators, one for the region and one for the gridded observations from the ANUSPLIN database. The station values tend to be a bit more extreme, as they represent results from one specific location. The regional values represent are somewhat attenuated by averaging across a number of grid cells within the region. As snowfall is not available from ANUSPLIN or from the downscaled model output directly, we have created a snow proxy instead. This is simply the total precipitation that falls during days when the minimum temperature is below zero.

Figure 3.10 Historic Monthly Average Precipitation in the Pine Pass Region



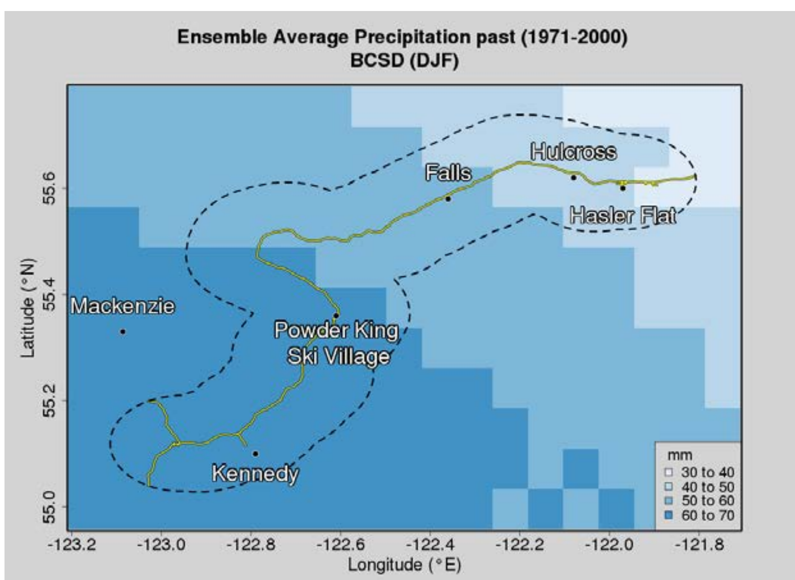


Table 3.8 Historic Pine Pass Climate Indicators

Precipitation	Value
Station Indicators	
Annual Total	682 mm/year
10-Year Return Period	41 mm/24hr
25-Year Return Period	56 mm/24hr
Snow Proxy	9 events/year
Regional Indicators	
Annual Total	653 mm/year
10-Year Return Period	35 mm/24hr
Snow Proxy	4 events/year

3.5.2 Future Climate

In the Pine Pass region we once again observe larger increases in winter. PCIC projects a shift in the timing of the largest summer precipitation from July to June. The winter precipitation increases are spread uniformly throughout the region, while the summer increases occur primarily in the northern stretches, moving onto the edge of the mountain range.

PCIC also projects corresponding increases in the precipitation indicators for the region with an increase in the annual total precipitation by 12%. The increase in extreme values for the 10 and 25 Year Return Periods is 20-24%, while 5-Day total precipitation is projected to increase by 11%.

We present the changes in precipitation indicators in **Table 3.9**. In **Figure 3.11** we present the monthly change in precipitation and in **Figures 3.12 and 3.13** we present the projected changes in precipitation for the summer and winter periods.

Table 3.9 Projected Changes in Precipitation – Pine Pass Region

Indicator	Past (1971-2000)	Future (2041-2070)	% Change
Annual Total (mm)	653	734	12
10-year Return Event (mm/24hr)	35	42	20
25-year Return Event (mm/24hr)	41	51	24
5-Day Precipitation (mm)	53	59	11

Figure 3.11 Projected Monthly Precipitation – Pine Pass

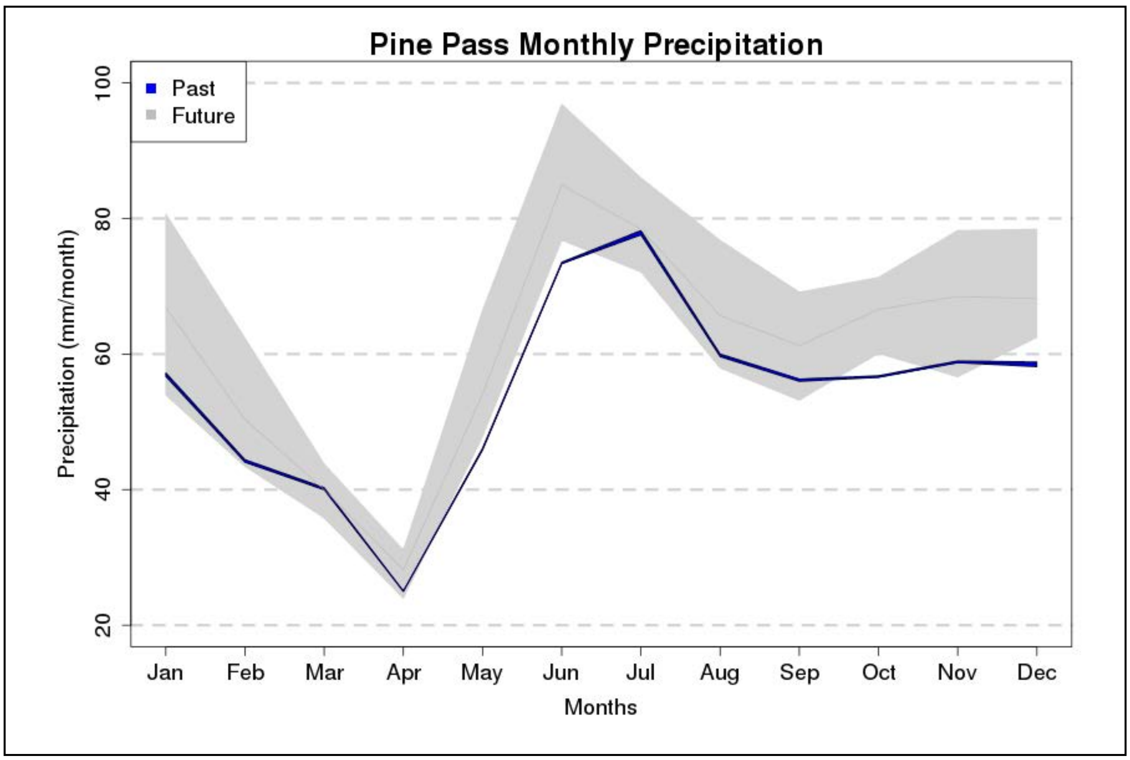


Figure 3.12 Projected % Change in Precipitation – Winter – Pine Pass

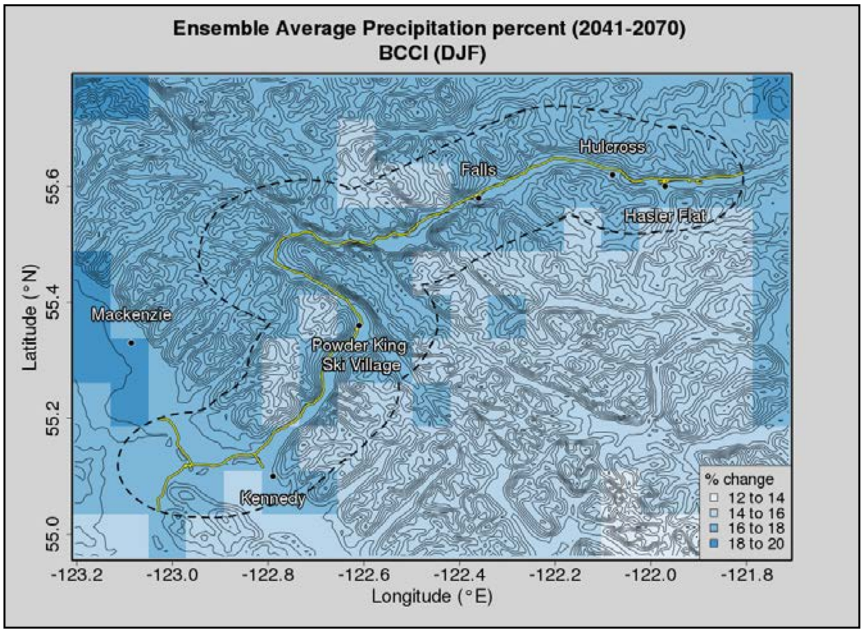
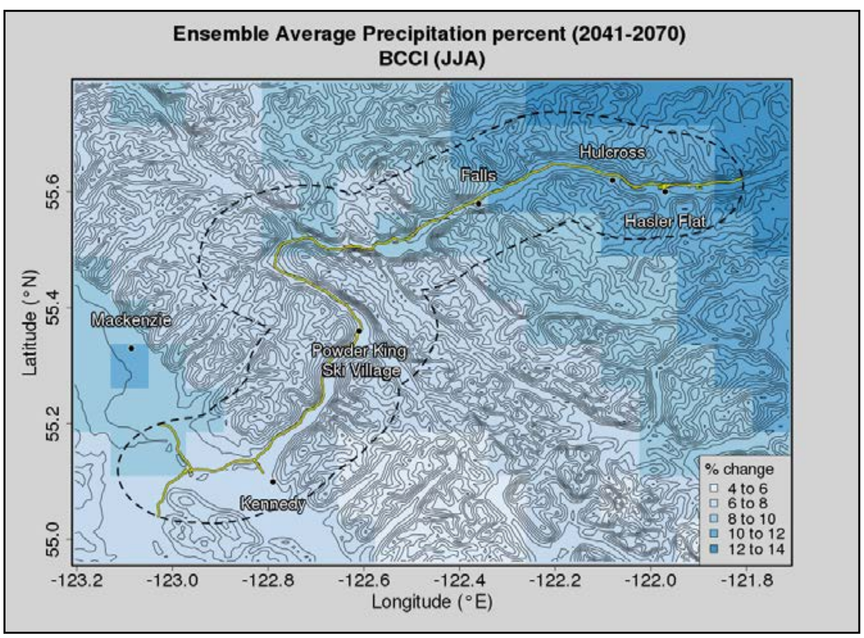


Figure 3.13 Projected % Change in Precipitation – Summer – Stewart (Bear Pass)



3.6 State the Timeframe

The team did not adjust the timeframe based on their deliberations in Step 2. The assessment timeframe is described in **Section 2.4**.

3.7 State the Geography

The team did not adjust the geographical definition based on their deliberations in Step 2. The assessment geography is described in **Section 2.5**.

3.8 State Specific Jurisdictional Considerations

The team did not adjust the jurisdictional considerations based on their deliberations in Step 2. The jurisdictional considerations are described in **Section 2.6**.

3.9 State Other Potential Changes that Affect the Infrastructure

The primary focus of this work was assessment of the impact of higher precipitation on the three highway segments. The team did not identify any other potential changes that could exacerbate the risks the assessment uncovered. The most significant impact on the highway drainage infrastructure systems was both a higher frequency of precipitation events and the increased likelihood of higher intensity events. This focus evolved out of the findings from the Coquihalla and Yellowhead Highway Vulnerability Assessments. Other factors were not deemed to have a significant impact on this determination.

3.10 Site Visits

As stated in **Section 2.7**, the team did not conduct site visits as part of this assessment. The team had sufficient day-to-day, hands-on, experience in managing, operating and maintaining the highway systems under evaluation that additional site visits were not deemed necessary to further the objectives of the assessment.

3.11 Assess Data Sufficiency

As indicated in **Section 3.2**, there is some uncertainty associated with establishing future climatic conditions. The team used a variety of approaches to establish future climate conditions. Each approach contained inherent uncertainties that were addressed by the team. However, the team concluded that the available climate data was sufficient to conduct the risk assessment.

4 Step 3 – Risk Assessment

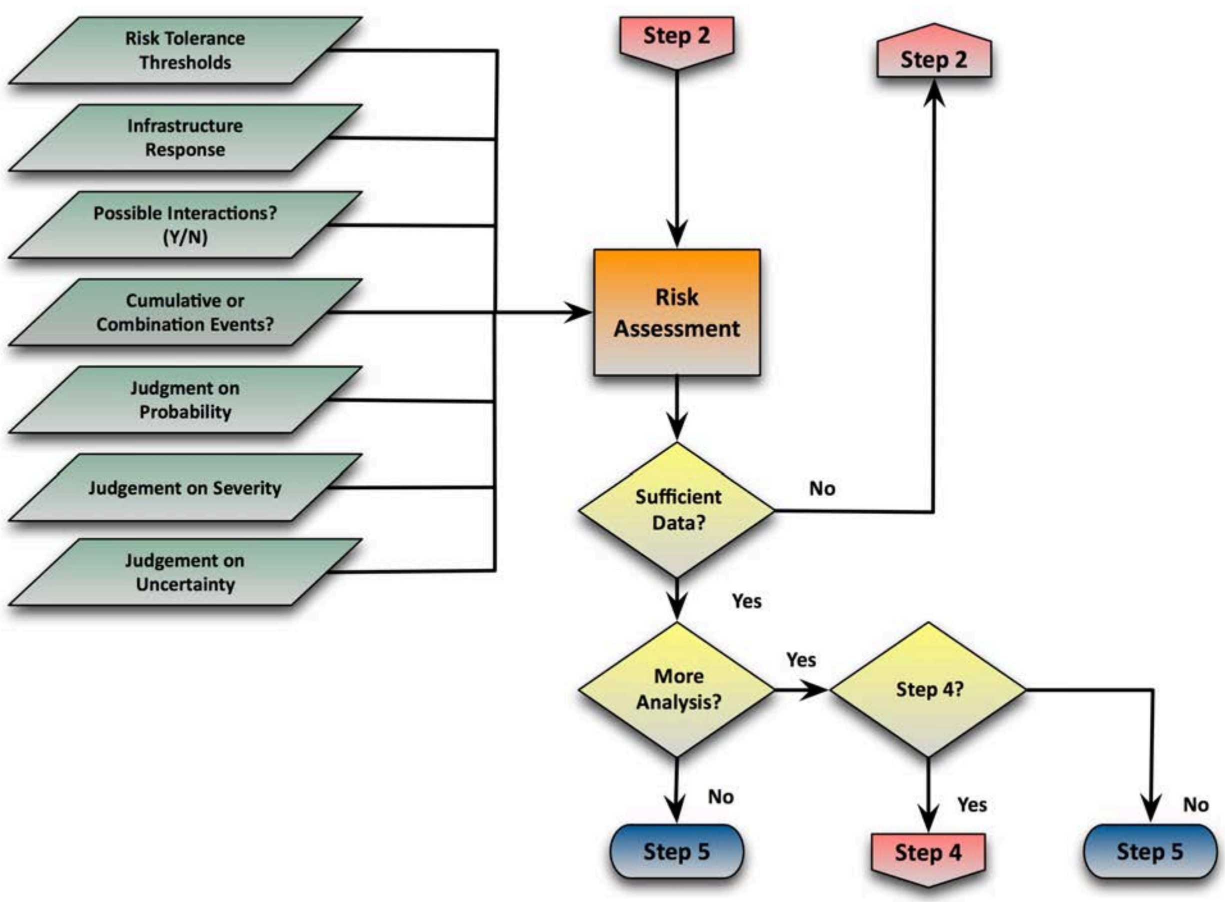
In this step the team identified the infrastructure's response to climate events. The protocol directed the team to develop:

- A list of relevant climate events; and
- A list of relevant infrastructure components.

The team examined interactions between infrastructure and climatic events that, potentially, could lead to vulnerability. Pairings between infrastructure components and climate events are called interactions.

The process flowchart for Step 3 of the protocol is presented in **Figure 4.1**.

Figure 4.1 Step 3 – Risk Assessment Process Flowchart



4.1 Consultation with Owner and Operations Personnel

BCMoTI drove the climate change risk assessment. Nodelcorp provided facilitation services and technical advice. Consequently, the project demanded a significant amount of consultation within the BCMoTI team and with PCIC to ensure that sufficient data was identified and defined to effectively conduct the two-day risk assessment workshop that formed the focus of this project. **Table 4.1** outlines the team's deliberation process from January through August 2013.

Table 4.1 Consultation Process

Date	Participants	Purpose
Jan 10	BCMoTI Team	▪ Project Kick Off
Feb 5	BCMoTI Team	▪ Identification of Key Project Deliverables and Timelines
Mar 5	BCMoTI Team	▪ PCIC scope identified ▪ Review Project Execution Plan
Apr 2	BCMoTI Team	▪ Review climate parameters ▪ Review Climate Primer document
May 7	BCMoTI Team	▪ Review Worksheet 1
Jun 4	BCMoTI Team	▪ Review Climate parameters ▪ Review Worksheet 2
Jul 10	BCMoTI Team	▪ Worksheet 2 review ▪ Worksheet 3 review ▪ Discussion of Probability Scoring ▪ Workshop logistics
Aug 1 & 2	BCMoTI Team	▪ Risk Assessment Workshop ▪ Face to Face meeting in Prince George

4.1.1 Risk Assessment Workshop

The Risk Assessment workshop was conducted over a two-day period on August 1 and 2, 2013. The team used this workshop to carry out the analysis defined by Step 3 of the Protocol. At the completion of the workshop the team had resolved the climate change risk profile for the three highway segments.

4.1.2 Owner's Risk Tolerance Thresholds

The Protocol directs the practitioner to confirm the infrastructure owner's risk tolerance thresholds prior to conducting the risk assessment. The Protocol suggests High, Medium and Low risk thresholds. On July 15, 2013 BCMoTI confirmed their acceptance of the risk thresholds defined by the Protocol for application in this process.

Table 4.2 outlines the risk thresholds used for this risk assessment.

Table 4.2 Historic Risk Tolerance Thresholds

Risk Range[2]	Threshold	Response
< 12	Low Risk	• No immediate action necessary
12 – 36	Medium Risk	• Action may be required • Engineering analysis may be required
> 36	High Risk	• Immediate action required

4.2 Risk Assessment Methodology

Based on the Protocol, the team developed a risk value for each of the climate-infrastructure interactions identified through Step 1 and 2 of the assessment. The Protocol defines a default risk assessment process is based on scales of 0 to 7**.** For each interaction, the team:

- Established the probability of the climate interaction occurring in a manner that may adversely affect the infrastructure;
  - Using a scale of 0 to 7, where:
    - 0 means that the adverse interaction will not occur in the timeframe of the assessment; and
    - 7 means certainty that the adverse interaction will occur in the timeframe of the assessment; and
- Established a severity resulting from the interaction;
  - Using a scale of 0 to 7, where
    - 0 means no negative consequences in the event that the interaction occurs; and
    - 7 means a significant failure will result if the interaction occurs.

[2] Risk scores range from 0 to 49 based on the 0-7 probability and severity scales used in the assessment.

Based on the protocol, the team selected the scale definitions for probability and severity that were applied consistently through the risk assessment process. **Table 4.3** presents the probability scaling definitions that were applied by the team. **Table 4.4** presents the severity definitions. These tables were extracted from the Protocol. The team applied the highlighted definitions. Alternative definitions, offered by the Protocol, are de-emphasized in the figures.

Table 4.3 Probability Scale Factors

Scale	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 Often	70 % 1 in 1.4
7	Highly Probable Approaching Certainty	> 99 % > 1 in 1.01

Table 4.4 Severity Scale Factors

Scale	Magnitude	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

Based on these probability and severity scales, the team calculated the climate change risk for each sub-component using the following equation:

$$R = P \times S$$

Where:

R = Risk
P = Probability of the interaction
S = Severity of the interaction

4.3 Infrastructure Response Analysis

The first step in assessing climate change risk is to identify the potential infrastructure responses for each infrastructure component considered in the assessment.

In establishing conceivable infrastructure responses the team considered the most likely response of each infrastructure component to contemplated climate events. This was based on the team's professional judgment and experience.

This analysis serves as a preliminary screening process. Any infrastructure component that exhibits no material performance response, in the judgment of the team, can be excluded from further assessment.

To aid in this assessment the team used the infrastructure response listing provided in Appendix B of the protocol. The list is presented in **Table 4.5**.

Table 4.5 Infrastructure Response Considerations

Infrastructure Response Category	Considerations
Structural Design	▪ Safety • Load carrying capacity • Overturning • Sliding • Fracture • Fatigue • Serviceability ▪ Deflection • Permanent deformation • Cracking and deterioration • Vibration ▪ Foundation Design • Permafrost
Functionality	▪ Effective Capacity of the infrastructure • Short term • Medium term • Long term ▪ Equipment - Component Selection • Design, process and capacity considerations
Serviceability	▪ Ability to conduct routine and/or planned maintenance

Table 4.5 Infrastructure Response Considerations

Infrastructure Response Category	Considerations
	and refurbishment activities • Short term • Medium term • Long term ▪ Equipment - Component Replacement frequencies • Design, process and capacity considerations
Watershed, Surface Water, and Groundwater	▪ Erosion along streams, rivers, and ditches ▪ Erosion scour of associated or supporting earthworks ▪ Slope stability of embankments ▪ Sediment transport and sedimentation ▪ Channel realignment / meandering ▪ Water quality ▪ Water quantity ▪ Water resource demands • Public, hydro, industrial, agricultural use of water resources • Groundwater recharge characteristics ▪ Run off ▪ Recharge ▪ Thermal characteristics of the water resource
Operations, Maintenance, and Materials Performance	▪ Occupational safety ▪ Access to worksite ▪ Structural integrity ▪ Equipment performance • Maintenance and replacement cycles • Electricity demand • Fuel use ▪ Functionality & Effective Capacity ▪ Materials Performance • Changes from design expectation ▪ Pavement performance • Hail, softening, cracking from freeze thaw and other causes
Emergency Response	▪ Procedures and systems to address: • Severe storm events • Flooding • Ice dams

Table 4.5 Infrastructure Response Considerations

Infrastructure Response Category	Considerations
	• Ice accretion • Water damage
Insurance Considerations	▪ Insurance rates ▪ The ability to acquire insurance ▪ Insurance policy limitations and exclusions
Policy Considerations	▪ Codes ▪ Guidelines ▪ Standards ▪ Internal operations and maintenance policies and procedures ▪ Public sector policy ▪ Land use planning
Social Effects	▪ Accessibility to critical facilities such as hospitals, fire and police services ▪ Transportation of goods to a community ▪ Energy supply to a community ▪ Dislocation of affected populations ▪ Provision of basic services such as potable water distribution and wastewater collection ▪ Closure of schools and other public services ▪ Community business viability ▪ Destruction or damage to heritage buildings, monuments, etc. ▪ Destruction or damage to archaeological resources ▪ Destruction or damage to historically important resources
Environmental Effects	▪ Release of toxic or controlled substances ▪ Degradation of air quality ▪ Damage to sensitive ecosystems ▪ Physical harm to birds and animals ▪ Contamination of potable water supplies ▪ Public perception and interaction

The final infrastructure response analysis for this risk assessment is presented in **Tables 4.6, 4.7 and 4.8**.

Table 4.6 Infrastructure Response Analysis – Bella Coola

	Infrastructure Components	Infrastructure Response Considerations									
		Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Insurance Considerations	Policy Considerations	Social Effects	Environmental Effects
		Mark Relevant Responses with ✓									
	Above Ground										
1	Shoulders (Including Gravel)		✓	✓		✓					
2	Curb (N/A)										
3	Ditches		✓	✓	✓	✓					
4	Embankments / Cuts	✓	✓	✓		✓	✓	✓		✓	✓
5	Natural Hillside/Slope Stability				✓	✓	✓			✓	✓
6	Protection Works / Armoring	✓	✓	✓	✓	✓	✓			✓	✓
7	Engineered Stabilization Works	✓	✓	✓	✓	✓	✓			✓	
8	Structures that Cross Streams	✓	✓	✓		✓	✓	✓	✓	✓	✓
9	Retaining Walls (N/A)										
	Below Ground										
10	Road Sub-Base	✓	✓	✓		✓					
11	Detail Drainage (N/A)										
12	Drainage Appliances (N/A)										
13	Sub Drains (N/A)										
14	Catch Basins (N/A)										
15	Grates (N/A)										
16	Culverts < 3 meters	✓	✓	✓	✓	✓	✓		✓	✓	✓
17	Culverts >3 meters	✓	✓	✓	✓	✓	✓		✓	✓	✓
18	Bridge End Fill	✓	✓	✓	✓	✓	✓		✓	✓	✓

Table 4.7 Infrastructure Response Analysis – Stewart (Bear Pass)

	Infrastructure Components	Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Insurance Considerations	Policy Considerations	Social Effects	Environmental Effects
		Mark Relevant Responses with ✓									
	Above Ground										
1	Shoulders (Including Gravel)		✓	✓		✓					
2	Curb (N/A)										
3	Ditches		✓	✓	✓	✓					
4	Embankments / Cuts	✓	✓	✓		✓	✓	✓		✓	✓
5	Natural Hillsides - Slope Stability				✓	✓	✓			✓	✓
6	Protection Works	✓	✓	✓	✓	✓	✓			✓	✓
7	Engineered Stabilization Works	✓	✓	✓	✓	✓	✓			✓	
8	Structures that Cross Streams	✓	✓	✓		✓	✓	✓	✓	✓	✓
9	Retaining Walls	✓	✓	✓		✓	✓	✓		✓	
	Below Ground										
10	Road Sub-Base	✓	✓	✓		✓					
11	Detail Drainage (N/A)										
12	Drainage Appliances (N/A)										
13	Sub Drains (N/A)										
14	Catch Basins (N/A)										
15	Grates (N/A)										
16	Culverts < 3 meters	✓	✓	✓	✓	✓	✓		✓	✓	✓
17	Culverts >3 meters	✓	✓	✓	✓	✓	✓		✓	✓	✓
18	Bridge End Fill	✓	✓	✓	✓	✓	✓			✓	

Table 4.8 Infrastructure Response Analysis – Pine Pass

	Infrastructure Components	Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Insurance Considerations	Policy Considerations	Social Effects	Environmental Effects
		Mark Relevant Responses with ✓									
	Above Ground										
1	Shoulders (Including Gravel)		✓	✓		✓					
2	Curb - Asphalt	✓	✓	✓		✓	✓				
3	Ditches		✓	✓	✓	✓					
4	Embankments / Cuts	✓	✓	✓		✓	✓	✓		✓	✓
5	Hillsides				✓	✓	✓			✓	✓
6	Protection Works	✓	✓	✓	✓	✓	✓			✓	✓
7	Engineered Stabilization Works	✓	✓	✓	✓	✓	✓			✓	
8	Structures that Cross Streams	✓	✓	✓		✓	✓	✓	✓	✓	✓
9	Retaining Walls	✓	✓	✓		✓	✓	✓		✓	
	Below Ground										
10	Road Sub-Base	✓	✓	✓		✓					
11	Detail Drainage (N/A)										
12	Drainage Appliances - Spillway	✓	✓	✓	✓	✓					
13	Sub Drains (N/A)										
14	Catch Basins	✓	✓	✓	✓	✓					✓
15	Grates (N/A)										
16	Culverts < 3 meters	✓	✓	✓	✓	✓	✓		✓	✓	✓
17	Culverts >3 meters	✓	✓	✓	✓	✓	✓		✓	✓	✓
18	Bridge End Fill	✓	✓	✓	✓	✓	✓		✓	✓	✓
19	3rd Party Utilities					✓	✓	✓	✓		
20	Railway					✓	✓	✓	✓		

4.4 Yes/No Analysis

The next step of the process is to assess the potential for adverse interactions between each climate parameter and each infrastructure component. At this stage of the process, the team is not assessing the magnitude of the risk. Rather, this is a second stage of screening. If the team determines that there can be an adverse interaction between a climatic parameter and an infrastructure component, the interaction is retained within the process for further risk analysis. If the team determines that there may be no material adverse impact, the interaction is eliminated from further risk assessment analysis.

The team completed the Yes/No analysis at the face-to-face workshop in Prince George on August 1 and 2, 2013.

The results from the Yes/No Analysis is presented in **Tables 4.9, 4.10 and 4.11**.

Table 4.9 Yes / No Analysis – Bella Coola

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
	Above Ground													
1	Shoulders (Including Gravel)		✓	✓	✓	✓	✓					✓		
2	Curb (N/A)					✓								
3	Ditches		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	
4	Embankments / Cuts	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	
5	Natural Hillside/Slope Stability	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	
6	Protection Works / Armoring	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
7	Engineered Stabilization Works	✓					✓			✓	✓	✓	✓	
8	Structures that Cross Streams		✓					✓		✓	✓	✓	✓	✓
9	Retaining Walls (N/A)													
	Below Ground													
10	Road Sub-Base											✓	✓	
11	Detail Drainabe (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
17	Culverts >3 meters		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
18	Bridge End Fill		✓		✓			✓		✓	✓	✓	✓	

Table 4.10 Yes / No Analysis – Stewart (Bear Pass)

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		R	R	R	R	R	R	R	R	R	R	R	R	R
	Above Ground													
1	Shoulders (Including Gravel)		✓	✓	✓	✓	✓					✓	✓	
2	Curb (N/A)													
3	Ditches		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	Embankments / Cuts	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
5	Natural Hillsides - Slope Stability	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
6	Protection Works	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
7	Engineered Stabilization Works	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓
8	Structures that Cross Streams		✓					✓	✓	✓	✓	✓	✓	✓
9	Retaining Walls		✓					✓	✓	✓	✓			✓
	Below Ground													
10	Road Sub-Base											✓	✓	
11	Detail Drainabe (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
17	Culverts >3 meters		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
18	Bridge End Fill		✓		✓			✓			✓	✓	✓	

Table 4.11 Yes / No Analysis –Pine Pass

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
	Above Ground													
1	Shoulders (Including Gravel)		✓	✓	✓	✓	✓				✓	✓	✓	
2	Curb - Asphalt					✓								
3	Ditches		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	
4	Embankments / Cuts	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	
5	Hillsides	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	
6	Protection Works	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
7	Engineered Stabilization Works	✓					✓			✓	✓	✓	✓	
8	Structures that Cross Streams		✓		✓			✓		✓	✓	✓	✓	✓
9	Retaining Walls													
	Below Ground													
10	Road Sub-Base				✓							✓	✓	
11	Detail Drainage (N/A)													
12	Drainage Appliances - Spillway		✓		✓			✓			✓			
13	Sub Drains (N/A)													
14	Catch Basins		✓		✓			✓						
15	Grates (N/A)													
16	Culverts < 3 meters		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
17	Culverts >3 meters		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
18	Bridge End Fill		✓		✓			✓		✓	✓	✓	✓	
19	3rd Party Utilities		✓		✓						✓	✓	✓	
20	Railway		✓		✓						✓	✓	✓	

4.5 Calculated Risk for Each Relevant Interaction

The team calculated the risk for each interaction in two steps. First, PCIC and representatives from the team with climate expertise consulted and assigned probabilities for the climate parameters. Second, at the workshop, the team assigned severity scores for each interaction that passed the Yes/No analysis.

4.5.1 Probability Scores

There are a number of possible ways to assess the climate change risk using this process. For example, in some studies the practitioner may calculate risk profiles for both the baseline climate and project future climate. Conversely, the team can assign a probability to the climate parameter changing in a manner that can adversely affect the infrastructure. In this case, the team calculates only one risk profile, that for the changing future climate. In this assessment, the team applied the second approach, calculating the risk profile for a future climate based on the projections and analysis provided by PCIC, synoptic and sensitivity analysis, as described in **Section 3**.

For this project, Nodelcorp Consulting Inc. conducted a preliminary probability scoring analysis for each of the highway segments that the team assessed. We conducted this analysis applying the principles outlined in Section 9.7 of ***the PIEVC Engineering Protocol – PRINCIPLES AND GUIDELINES – Revision PG-10.1 (Publication Pending)***. This work was completed in worksheets provided within the Protocol and then shared with the BCMoTI team prior to the August Workshop. These workbooks have been retained as key elements of the working papers that support this assessment and have been provided to BCMoTI under separate cover. At the workshop, the team reviewed the probability scores in detail and made adjustments based on the professional judgment of the overall team.

In order to assign probability scores, the team considered the following factors:

A: Will climate conditions, relevant to the infrastructure, change over the time horizon of the assessment?

- Yes
- No

B: Will thresholds be triggered more often, the same as, or less than current operation?

- + = More
- 0 = Same
- - = Less

C: What is the impact of the projected change in magnitude of the climate event on the frequency of trigger events?

- H = High
- M = Medium
- L = Low
- Not Applicable

D: What is the projected impact of the change in frequency of climate events on the frequency of trigger events?

- H = High
- M = Medium
- L = Low
- Not Applicable

E: How robust are the results of the climate forecasts?

- H = High
- M = Medium
- L = Low

The final probability score is a function of all of the input parameters that the team considered.

$$P = f\ (A, B, C, D, \&\ E)$$

There is no quantitative methodology for executing this analysis. Rather, the team must weigh:

- Each factor; and
- The influence of the factors on each other.

Based on this evaluation the team can make an informed decision regarding the overall probability score.

The score is a team-assigned value reflecting the probability of changing climate causing a change in threshold triggering events.

The team reviewed available climate data, synoptic analysis and sensitivity considerations and then expressed a professional opinion based on the consensus of the team. They also assessed the nature of the change in climate, whether the anticipated change was better or worse for the infrastructure, the likely magnitude of that change and their overall confidence in the assessment based on the data availability and approaches used.

The results of these deliberations are outlined in **Tables 4.12, 4.13 and 4.14**.

Table 4.12 Probability Scores – Bella Coola

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		P	P	P	P	P	P	P	P	P	P	P	P	P
	Above Ground													
1	Shoulders (Including Gravel)		6	7	5	3	6					6		
2	Curb (N/A)					3								
3	Ditches		6	7	5	3	6	5		4	6	6	5	
4	Embankments / Cuts	2	6	7	5		6	5		4	6	6	5	
5	Natural Hillside/Slope Stability	2	6	7	5		6	5		4	6	6	5	
6	Protection Works / Armoring	2	6	7	5		6	5		4	6	6	5	1
7	Engineered Stabilization Works	2					6			4	6	6	5	
8	Structures that Cross Streams		6					5		4	6	6	5	1
9	Retaining Walls (N/A)													
	Below Ground													
10	Road Sub-Base											6	5	
11	Detail Drainage (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		6	7	5			5	4	4	6	6	5	1
17	Culverts >3 meters		6	7	5			5	4	4	6	6	5	1
18	Bridge End Fill		6		5			5		4	6	6	5	

Table 4.13 Probability Scores – Stewart (Bear Pass)

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		P	P	P	P	P	P	P	P	P	P	P	P	P
	Above Ground													
1	Shoulders (Including Gravel)		6	7	5	3	7					6	5	
2	Curb (N/A)													
3	Ditches		6	7	5	3	7	6	4	4	6	6	5	1
4	Embankments / Cuts	2	6	7	5		7	6	4	4	6	6	5	1
5	Natural Hillsides - Slope Stability	7	6	7	5		7	6	4	4	6	6	5	1
6	Protection Works	2	6	7	5		7	6	4	4	6	6	5	1
7	Engineered Stabilization Works	2	6				7		4	4	6	6	5	1
8	Structures that Cross Streams		6					6	4	4	6	6	5	1
9	Retaining Walls		6					6	4	4	6			1
	Below Ground													
10	Road Sub-Base											6	5	
11	Detail Drainage (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		6	7	5			6	4	4	6	6	5	1
17	Culverts >3 meters		6	7	5			6	4	4	6	6	5	1
18	Bridge End Fill		6		5			6			6	6	5	

Table 4.14 Probability Scores – Pine Pass

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		P	P	P	P	P	P	P	P	P	P	P	P	P
	Above Ground													
1	Shoulders (Including Gravel)		7	7	6	3	6				5	7	6	
2	Curb - Asphalt					3								
3	Ditches		7	7	6	3	6	4		4	5	7	6	
4	Embankments / Cuts	2	7	7	6		6	4		4	5	7	6	
5	Hillsides	4	7	7	6		6	4		4	5	7	6	
6	Protection Works	2	7	7	6		6	4		4	5	7	6	1
7	Engineered Stabilization Works	2					6			4	5	7	6	
8	Structures that Cross Streams		7		6			4		4	5	7	6	1
9	Retaining Walls													
	Below Ground													
10	Road Sub-Base				6							7	6	
11	Detail Drainage (N/A)													
12	Drainage Appliances - Spillway		7		6			4			5			
13	Sub Drains (N/A)													
14	Catch Basins		7		6			4						
15	Grates (N/A)													
16	Culverts < 3 meters		7	7	6			4	4	4	5	7	6	1
17	Culverts >3 meters		7	7	6			4	4	4	5	7	6	1
18	Bridge End Fill		7		6			4		4	5	7	6	
19	3rd Party Utilities		7		6						5	7	6	
20	Railway		7		6						5	7	6	

4.5.2 Severity Scores

The team assigned the severity score for each relevant climate-infrastructure interaction at the workshop in early August. The implications and potential consequences for each interaction were discussed in turn by the team. As previously indicated, the team would occasionally refer back to the performance response considerations to inform these discussions.

In some ways, the assignment of severity scores was much more straightforward than the assignment of probability scores. The team has direct, hands-on, experience in managing similar events over the life of the highway. This experience provides a solid foundation for the opinions expressed by the team membership.

During the workshop, there were occasions where team members would disagree about potential outcomes of a particular interaction. However, the team was able to fully examine these situations and arrive at a consensus regarding the severity scoring.

It is notable that the team assigned a number of severity scores of “0”. This is permitted by the Protocol. This allows a further level of screening and review. These items initially passed the Yes/No analysis but, upon more detailed review, were determined to have immaterial adverse outcomes from the climate-infrastructure interaction. This ensures that the assignment of a low risk score was based on a considered evaluation of the situation.

The severity scores assigned by the team are presented in **Tables 4.15, 4.16 and 4.17**.

Table 4.15 Severity Scores – Bella Coola

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		S	S	S	S	S	S	S	S	S	S	S	S	S
	Above Ground													
1	Shoulders (Including Gravel)		4	1	4	1	2					4		
2	Curb (N/A)					1								
3	Ditches		2	1	2	1	2	3		0	3	3	3	
4	Embankments / Cuts	4	3	1	3		2	1		0	2	6	6	
5	Natural Hillside/Slope Stability	5	4	1	4		2	1		0	2	6	6	
6	Protection Works / Armoring	3	5	1	5		2	4		0	5	7	7	1
7	Engineered Stabilization Works	2					2			0	1	1	1	
8	Structures that Cross Streams		4					4		0	4	3	3	1
9	Retaining Walls (N/A)													
	Below Ground													
10	Road Sub-Base											6	6	
11	Detail Drainage (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		4	1	4			3	1	0	4	6	6	1
17	Culverts >3 meters		5	1	5			3	1	0	3	3	3	1
18	Bridge End Fill		6		6			5		0	6	7	7	

Table 4.16 Severity Scores – Stewart (Bear Pass)

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		S	S	S	S	S	S	S	S	S	S	S	S	S
	Above Ground													
1	Shoulders (Including Gravel)		4	1	4	1	1					4	4	
2	Curb (N/A)													
3	Ditches		2	1	2	1	1	3	0	0	3	3	3	1
4	Embankments / Cuts	4	3	1	3		1	1	0	0	2	6	6	1
5	Natural Hillsides - Slope Stability	3	4	1	4		1	1	0	0	2	6	6	1
6	Protection Works	3	5	1	5		1	4	0	0	5	7	7	1
7	Engineered Stabilization Works	2	3				1		0	0	1	1	1	1
8	Structures that Cross Streams		4					4	0	0	4	3	3	1
9	Retaining Walls		1					1	0	0	1			1
	Below Ground													
10	Road Sub-Base											6	6	
11	Detail Drainage (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		4	1	4			3	0	0	4	6	6	1
17	Culverts >3 meters		5	1	5			3	0	0	3	3	3	1
18	Bridge End Fill		6		6			4			6	7	7	

Table 4.17 Severity Scores – Pine Pass

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		S	S	S	S	S	S	S	S	S	S	S	S	S
	Above Ground													
1	Shoulders (Including Gravel)		4	1	4	1	2				2	4	4	
2	Curb - Asphalt					1								
3	Ditches		2	1	2	1	2	2		0	2	4	4	
4	Embankments / Cuts	5	3	1	4		2	1		0	2	7	7	
5	Hillsides	5	5	1	4		2	1		0	2	7	7	
6	Protection Works	3	6	1	6		2	3		0	3	6	6	1
7	Engineered Stabilization Works	2					2			0	1	2	2	
8	Structures that Cross Streams		5		6			3		0	3	7	7	1
9	Retaining Walls													
	Below Ground													
10	Road Sub-Base				3							6	6	
11	Detail Drainage (N/A)													
12	Drainage Appliances - Spillway		2		3			3			3			
13	Sub Drains (N/A)													
14	Catch Basins		2		2			3						
15	Grates (N/A)													
16	Culverts < 3 meters		5	1	5			3	1	0	4	7	7	1
17	Culverts >3 meters		5	1	5			3	1	0	4	6	6	1
18	Bridge End Fill		7		7			3		0	6	7	7	
19	3rd Party Utilities		7		7						3	7	7	
20	Railway		2		2						3	1	1	

4.5.3 Risk Outcomes

Based on the probability and severity scores, the team calculated the risk outcomes using the equation described in **Section 4.2**:

$$R = P \times S$$

Where:

R = Risk
P = Probability of the interaction
S = Severity of the interaction

Each outcome was assigned a high, medium or low risk score based on the risk tolerances defined in **Section 4.1.2** and color-coded, as indicated in **Table 4.18.**

Table 4.18 Risk Tolerance Threshold Color Codes

Risk Range	Threshold	Response
< 12	Low Risk	• No immediate action necessary
12 – 36	Medium Risk	• Action may be required • Engineering analysis may be required
> 36	High Risk	• Immediate action required

The calculated risk scores arising from this assessment are presented in **Tables 4.19, 4.20 and 4.21**.

Table 4.19 Risk Scores – Bella Coola

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
	Above Ground													
1	Shoulders (Including Gravel)		24	7	20	3	12					24		
2	Curb (N/A)					3								
3	Ditches		12	7	10	3	12	15		0	18	18	15	
4	Embankments / Cuts	8	18	7	15		12	5		0	12	36	30	
5	Natural Hillside/Slope Stability	10	24	7	20		12	5		0	12	36	30	
6	Protection Works / Armoring	6	30	7	25		12	20		0	30	42	35	1
7	Engineered Stabilization Works	4					12			0	6	6	5	
8	Structures that Cross Streams		24					20		0	24	18	15	1
9	Retaining Walls (N/A)													
	Below Ground													
10	Road Sub-Base											36	30	
11	Detail Drainage (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		24	7	20			15	4	0	24	36	30	1
17	Culverts >3 meters		30	7	25			15	4	0	18	18	15	1
18	Bridge End Fill		36		30			25		0	36	42	35	

Table 4.20 Risk Scores – Stewart (Bear Pass)

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
		R	R	R	R	R	R	R	R	R	R	R	R	R
	Above Ground													
1	Shoulders (Including Gravel)		24	7	20	3	7					24	20	
2	Curb (N/A)													
3	Ditches		12	7	10	3	7	18	0	0	18	18	15	1
4	Embankments / Cuts	8	18	7	15		7	6	0	0	12	36	30	1
5	Natural Hillsides - Slope Stability	21	24	7	20		7	6	0	0	12	36	30	1
6	Protection Works	6	30	7	25		7	24	0	0	30	42	35	1
7	Engineered Stabilization Works	4	18				7		0	0	6	6	5	1
8	Structures that Cross Streams		24					24	0	0	24	18	15	1
9	Retaining Walls		6					6	0	0	6			1
	Below Ground													
10	Road Sub-Base											36	30	
11	Detail Drainage (N/A)													
12	Drainage Appliances (N/A)													
13	Sub Drains (N/A)													
14	Catch Basins (N/A)													
15	Grates (N/A)													
16	Culverts < 3 meters		24	7	20			18	0	0	24	36	30	1
17	Culverts >3 meters		30	7	25			18	0	0	18	18	15	1
18	Bridge End Fill		36		30			24			36	42	35	

Table 4.21 Risk Scores – Pine Pass

	Infrastructure Components	1 Total Annual Rainfall	2 Extreme High Rainfall	3 Light Sustained Rainfall	4 Heavier Sustained Rainfall	5 Snow (Frequency)	6 Snow Accumulation	7 Rain on Snow	8 Rain on Frozen Ground	9 Rapid Snow Melt	10 Snowmelt Driven Peak Flow Events	11 Magnitude of Storm Driven Peak Flow Events	12 Frequency of Storm Driven Peak Flow Events	13 Ice / Ice Jams
	Above Ground													
1	Shoulders (Including Gravel)		28	7	24	3	12				10	28	24	
2	Curb - Asphalt					3								
3	Ditches		14	7	12	3	12	8		0	10	28	24	
4	Embankments / Cuts	10	21	7	24		12	4		0	10	49	42	
5	Hillsides	20	35	7	24		12	4		0	10	49	42	
6	Protection Works	6	42	7	36		12	12		0	15	42	36	1
7	Engineered Stabilization Works	4					12			0	5	14	12	
8	Structures that Cross Streams		35		36			12		0	15	49	42	1
9	Retaining Walls													
	Below Ground													
10	Road Sub-Base				18							42	36	
11	Detail Drainage (N/A)													
12	Drainage Appliances - Spillway		14		18			12			18			
13	Sub Drains (N/A)													
14	Catch Basins		14		12			12						
15	Grates (N/A)													
16	Culverts < 3 meters		35	7	30			12	4	0	20	49	42	1
17	Culverts >3 meters		35	7	30			12	4	0	20	42	36	1
18	Bridge End Fill		49		42			12		0	30	49	42	
19	3rd Party Utilities		49		42						15	49	42	
20	Railway		14		12						15	7	6	

4.5.4 Sensitivity Analysis

During the preliminary stages of this risk assessment we had contemplated applying sensitivity analysis to resolve potential risks for Ice/Ice Jams. However, at the workshop in early August, the team deemed that this climate factor did not present a material risk on any of the highway segments considered in this assessment. In all cases, the risks associated with ice and ice jams were determined to be very low. Based on this assessment, we concluded that additional sensitivity analysis on this parameter was not required.

4.6 Potential Cumulative Effects

The team contemplated several combined events and cumulative impacts in their assessment.

These included:

- Rain on Snow
  - Rain on snow including higher temperatures and wind considerations

- Rain on Frozen Ground
  - Represents the impact of rain falling on frozen surfaces
  - These events could lead to ice accretion and traffic safety concerns.

- Rapid Snow Melt
  - Direct impacts of snowmelt on highway infrastructure elements

- Snowmelt Driven Peak Flow Events
- Magnitude of Snowmelt Driven Peak Flow Events
- Frequency of Snowmelt Driven Peak Flow Events
  - Impact of snowmelt increasing contributing to water flow through the creeks and rivers in the region (Freshet)
  - These three parameters were evaluated sequentially to assess the combined effects of frequency and magnitude on the severity of the outcomes.

The above considerations identified a number of risks that would not otherwise have been resolved. In particular, considerations around Snowmelt Driven Peak Flow Events identified consistently significant risks for all three highway segments.

4.7 Items Forwarded to Step 4 – Engineering Analysis

The risk assessment did not identify infrastructure parameters that required Engineering Analysis to further resolve the risk profile. However, all three of these highway segments have experienced significant service interruptions arising from extreme rainfall events in recent years. Based on the experiences gained from these events, BCMoTI has decided to conduct some additional engineering analysis of the infrastructure components most severely affected by these incidents. Based on this work, they aim to:

- Gain an enhanced understanding of the circumstances that contributed to the service interruptions, both climatic and those related to infrastructure design, operation and maintenance; and
- Evaluate and predict risk outcomes from future climate conditions based on applying the PIEVC Step 4 (Engineering Analysis) process on select infrastructure components that have previously failed as a result of climate events.

The results of this work will be documented under separate cover and will not form an element of this present report.

4.8 Data Sufficiency

The team was satisfied with the quality, quantity and integrity of the data used for the risk assessment.

In general, the experience of the team compensated for any gaps in technical or design data.

4.9 Risk Ranking

4.9.1 General

The team ranked risks into three categories:

1. Low or No Material Risk
2. Medium Risk
3. High Risk

The team originally conducted the risk assessment on 728 potential climate-infrastructure interactions over three highway segments, as follows:

- Bella Coola - 234 climate-infrastructure interactions;
- Stewart (Bear Pass) - 234 climate-infrastructure interactions; and
- Pine Pass – 260 climate-infrastructure interactions.

Based on the analysis the team identified that:

- Yes/No analysis eliminated 422 of the potential interactions from further evaluation:
  - Bella Coola: 144
  - Stewart: 128
  - Pine Pass: 150

- 127 of the 338 interactions surviving Yes/No analysis had low or no material risk:
  - Bella Coola: 35
  - Stewart: 54
  - Pine Pass: 38

- 138 of the 338 interactions surviving Yes/No analysis had medium risk:
  - Bella Coola: 53

  - Stewart: 50
  - Pine Pass: 52

- 41of the 338 interactions surviving Yes/No analysis had high risk:
  - Bella Coola: 2
  - Stewart: 2
  - Pine Pass: 20

Over the three highway segments the overall pattern of the risk profile was very similar. Pine Pass, although exhibiting the same general pattern of risk, tended to demonstrate the most intense risk responses. This arose from a combination of the geomorphology of the Pine Pass region and also the specific design features of this particular highway segment. However, overall all three highway segments exhibited higher risks associated with two categories of climatic conditions. First, extreme high rainfall events tended to result in projected adverse infrastructure responses. Second, the impact of freshet conditions on the highway segments also resulted in higher levels of overall risk. These features are discussed in further detail in **Sections 4.9.2 and 4.9.3**.

4.9.2 Extreme Precipitation Events

Extreme rainfall events were identified as a high risk for all three highway segments. This pattern emerged for both one-time, high intensity, events as well as for sustained heavy rainfall. Such events were found to present risk to drainage features such as culverts, but also to slope stability and protection works. In the coastal regions of B.C. these incidents can be tracked to atmospheric river events, such as the Pineapple Express.

Pineapple Express events present a significant risk to the infrastructure in terms of drainage management issues. These can adversely affect the safety and serviceability of the infrastructure. The team raised concern that these events will increase in both frequency and magnitude. Furthermore, the infrastructure is already exhibiting vulnerability to high intensity rainfall events. Thus, the team concluded that these issues will be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highway.

4.9.3 Freshet

The other area of concern identified through this assessment was vulnerability to Snowmelt Driven Peak Flow Events (Freshet). These events have presented difficulties to the highway infrastructure in the past. The team anticipates that there will be more precipitation in the winter months in all three of these regions and that spring may come earlier and with greater overall intensity. Based on these considerations, the team projected that both the frequency and magnitude of such events would increase over the time horizon of the assessment. This resulted in higher risk scores for drainage features such as culverts and associated higher risk scores for slope stability and protection works.

4.9.4 Low Probability – High Severity Events

The PIEVC Protocol directs practitioner teams to pay particular attention to situations characterized by probability scores of "1" and severity scores of "7". The risk score is "7", which indicates low risk. However, should these events actually occur they are potentially devastating, resulting loss of asset or even loss of life. Given the severity and the fact that the team deems the event to be possible, even if unlikely, warrants special attention. The Protocol requires that these cases pass one additional level of scrutiny.

We have reviewed the raw risk assessment probability and severity scores for all three highway segments. The team identified no risk interactions that would deem further analysis based on extremely severe – low probability events.

5 Step 4 – Engineering Analysis

As previously outlined in **Section 4.7**, the risk assessment did not identify infrastructure parameters that required Engineering Analysis to further resolve the risk profile. However, all three of these highway segments have experienced significant service interruptions arising from extreme rainfall events in recent years. Based on the experiences gained from these events, BCMoTI has decided to conduct some additional engineering analysis of the infrastructure components most severely affected by these incidents. Based on this work, they aim to:

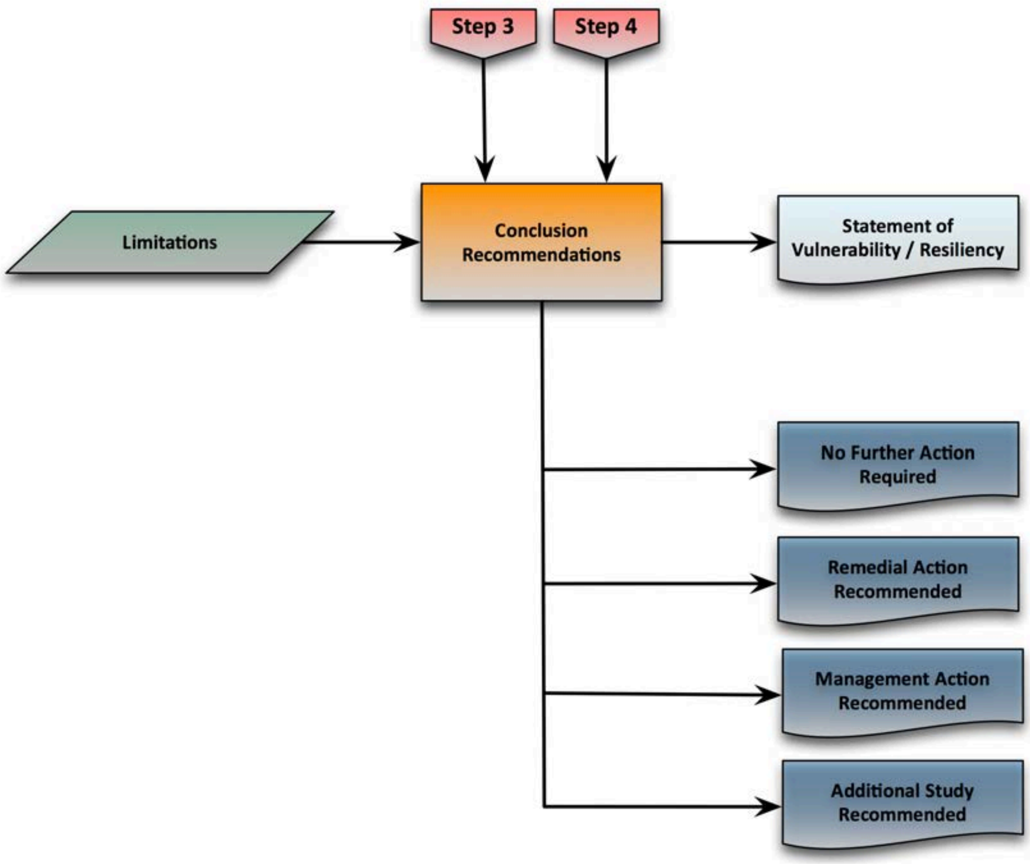
- Gain an enhanced understanding of the circumstances that contributed to the service interruptions, both climatic and those related to infrastructure design, operation and maintenance; and
- Evaluate and predict risk outcomes from future climate conditions based on applying the PIEVC Step 4 (Engineering Analysis) process on select infrastructure components that have previously failed as a result of climate events.

The results of this work will be documented under separate cover and will not form an element of this present report.

6 Step 5 – Recommendations

The process flowchart for Step 5 of the Protocol is presented in **Figure 6.1**.

Figure 6.1 Recommendations Process Flowchart



6.1 *Limitations*

6.1.1 Major Assumptions

The assessment was not limited by the project definition or stated timeframe. The highways are subjected to ongoing maintenance that would tend to mitigate many of the identified climate change risks as practices typically evolve to accommodate current conditions.

6.1.2 Available Infrastructure Information

The assessment was not limited by lack of technical information regarding the highways. The team had access to personal files and very deep experience with the design, operation and maintenance of the highways.

6.1.3 Available Climate Data

a) Ice/Ice Jams

PCIC was unable to provide model-based data for the Ice / Ice Jams climate parameter during the timeframe of the study.

During the preliminary stages of this risk assessment we had contemplated applying sensitivity analysis to resolve potential risks for Ice/Ice Jams. However, at the workshop in early August, the team deemed that this climate factor did not present a material risk on any of the highway segments considered in this assessment. In all cases, the risks associated with ice and ice jams were determined to be very low. Based on this assessment, we concluded that additional sensitivity analysis on this parameter was not required.

b) Freshet

PCIC could not provide climate model data for:

- Snowmelt Drive Peak Flow Events;
- Magnitude of Snow Driven Peak Flow Events; and
- Frequency of Snow Driven Peak Flow Events.

The team assessed the risk profiles for these events based on the overall professional experience of the team. This analysis was based on many years of managing such events and extrapolation of the precipitation information provided by PCIC for:

- Extreme High Rainfall; and

- Snow Frequency; and
- Snow Accumulation.

The experience of the team, and observations of day-to-day operation of the highway compensate for any gaps that may otherwise occur.

6.1.4 Available Information on Other Change Effects

The assessment was not limited by lack of information regarding other sources of change. The experience of the team, and observations of day-to-day operation of the highway compensate for any gaps that may otherwise occur.

6.1.5 Uncertainty

Climate modeling is based on inherent assumptions regarding likely CO_2 emissions scenarios. Additionally, there is a significant level of uncertainty associated with both the modeling and the analytical approaches used to downscale the information generated by the regional climate models to local conditions. PCIC addressed this concern by correlating model predictions with observed, baseline, climate conditions.

The BC MoTI team possesses a significant level of understanding of the regional climate based on many years of day-to-day, hands-on, experience with the design, operation and maintenance of the highway. This experience provided the team with sufficient foundation to assess the veracity of the climate model projections.

6.2 *Recommendations*

The recommendations arising from this risk assessment are outlined in **Table 6.1**.

Table 6.1 Recommendations

Remedial Engineering Action	Management Action	Additional Study Required
<u>Higher Rainfall</u> Higher levels of anticipated rainfall present a significant risk to the infrastructure in terms of drainage management issues. These can adversely affect the safety and serviceability of the infrastructure. The infrastructure is already exhibiting vulnerability to high intensity rainfall events. Thus, the team concluded that these issues may be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highways.		
1. BC MoTI should investigate current design reserve capacity of the highways to handle changing hydrology from increased local extreme rainfall events. 2. If, due to study findings, infrastructure components require upgrading to accommodate increased rainfall intensity, this should be accomplished as a part of regular design and maintenance activities and not as a separate program - unless a serious situation is identified (as forecast changes are 40+ years into future).	3. BC MoTI should require contractors to document weather conditions that caused major maintenance issues. Notionally, this would include meteorological data on rainfall, wind, etc. from the nearest weather station. This would link infrastructure problems with climate data and facilitate future monitoring of this interaction. 4. Investigate infrastructure failure models that contemplate climate as a variable and if they can be adapted to BC MoTI's requirements.	5. Develop guidelines for consultants and designers to account for the future influence of climate change and direct that this be incorporated and documented in highway infrastructure design work. For example, develop ***Best Practices*** and issue a ***Technical Circular*** for guidance to consultants on using future climate information in design. 6. Develop relevant, practical design parameters or proxies using available climate information to understand climate dynamics and relationships with infrastructure to instruct design accommodating climate change. For example, develop research into relationships and proxies. It is currently difficult to account for the effect of increased magnitude and frequency of rainfall on extreme stream peak flows, as it is not a

Table 6.1 Recommendations

Remedial Engineering Action	Management Action	Additional Study Required
		linear relationship. Future hydrotechnical design may require more complex engineering such as continuous rainfall analysis and watershed modeling. 7. Differencing geomorphologies can create very different risk outcomes for very similar climate events. BCMoTI should develop a methodology to index areas of increased geomorphological vulnerability; making a highway susceptible to debris flows in extreme precipitation events.
<u>Freshet</u> All three highway segments exhibited high-risk profiles associated with Snowmelt Driven Peak Flow Events, both in terms of potentially increasing magnitude and the frequency of such freshet events. These can adversely affect the safety and serviceability of the infrastructure. The infrastructure is already exhibiting vulnerability to freshet events. Thus, the team concluded that these issues may be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highways.		
8. BC MoTI should investigate current design reserve capacity of the highways to handle changing hydrology from increasing frequency and intensity of freshet events. 9. If, due to study findings, infrastructure components	10. BC MoTI should require contractors to document weather conditions that caused major maintenance issues arising from freshet event. Notionally, this would include meteorological data on snowfall, daily temperature profiles, etc. from the nearest	**N/A**

Table 6.1 Recommendations

Remedial Engineering Action	Management Action	Additional Study Required
require upgrading to accommodate increased freshet intensity and frequency, this should be accomplished as a part of regular design and maintenance activities and not as a separate program - unless a serious situation is identified (as forecast changes are 40+ years into future).	weather station. This would link infrastructure problems with climate data and facilitate future monitoring of this interaction.	

7 Closing Remarks

7.1 Statement of Vulnerability/Resiliency

With the exception of four specific risk issues, the three highway infrastructure systems considered in this vulnerability assessment are generally resilient to changing climate impacts associated with changes in precipitation patterns anticipated over the next thirty to seventy years.

Higher risk profiles were identified for stabilization works, embankments, culverts and some bridge structures with respect to anticipated higher rainfall patterns and increased frequency and intensity of freshet events. All three highway segments already exhibit a degree of vulnerability to these conditions and the assessment team anticipates the three highway segments to exhibit increased sensitivity to such conditions over the time horizon of this assessment.

We have based this opinion on climate information provided to the team by PCIC at the time of the assessment and the overall professional judgment and expertise of the BCMoTI assessment team. As climate change information for these regions evolves, it will be necessary to revisit and revise these assessment conclusions based on both improved understanding of changing climatic conditions and the responses of the highway systems to weather events.

7.2 Adaptive Management Process

BCMoTI initiated this study as the third phase of an ongoing climate change adaptive management process. Through this study BCMoTI:

- Assessed the climate change vulnerability of a portions of the B.C highway system in the;
  - Bella Coola region;
  - Stewart (Bear Pass) region; and
  - Pine Pass;
- Refined infrastructure component lists initially developed for the Coquihalla and Yellowhead Highway Assessments resulting in a component listing suitable for application on other BCMoTI highway vulnerability assessments;
- Refined skills and expertise in using the PIEVC assessment process; and
- Developed a solid foundation for further vulnerability assessments on other infrastructure;
- Included a hydrologic modeling analysis component in the Engineering Analysis

BC MoTI conducted this assessment using internal resources as well as the expertise of the Pacific Climate Impact Consortium, with facilitation by Nodelcorp Consulting Inc. The result of the approach is to understand climate change vulnerability using an assessment tool (PIEVC); and how this understanding can be integrated into the general understanding of staff responsible for the highway infrastructure and imbedded into design, management and operations activities.

As part of their ongoing work on climate change adaptation, BC MoTI has established an exemplary working relationship with the Pacific Climate Impacts Consortium at the University of Victoria. Through this relationship, climate parameters and data requirements have been refined to support further vulnerability assessment work. Also, these studies enable understanding of climate implications for BCMoTI to consider in future studies to lead to improved design standards and safer highway infrastructure.

7.3 Comparison with Coquihalla and Yellowhead Highway Vulnerability Assessments

This assessment was the third of a series of highway infrastructure climate change vulnerability assessments conducted by BCMoTI. The first assessment was on the Coquihalla Highway while the second was on the Yellowhead Highway.

The current study focused on three highway segments establishing a geographic grid of assessment results across the Province of British Columbia. The grid covers as broad a range of geomorphic and climate conditions as possible, across the five highway segments. Additionally, the current assessment focused on precipitation events based on the findings from the earlier assessments where precipitation/drainage issues were found to generate the highest levels of climate change vulnerability risk.

The current study confirmed the overall sensitivity of BC highway infrastructure to higher precipitation events. Coastal locations are somewhat more vulnerable to anticipated changes in the Pineapple Express atmospheric river phenomena while inland infrastructure systems may experience similar vulnerabilities arising from convective atmospheric events in conjunction with coastal atmospheric river events carrying more water vapour inland. Given the mountainous geography of B.C., all of the highway segments examined exhibited vulnerability to freshet conditions (snowmelt driven peak flow events). Freshet conditions generated risk profiles very similar to the risks associated with extreme precipitation, generally increased risk of failure of drainage appliances, culverts and stabilization works.