Climate Change Engineering Vulnerability Assessment of Transportation Infrastructure in British Columbia

Phase II

by

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Abstract

In December of 2009 the BC Provincial government put into place a BC Climate Adaptation Strategy. The Strategy calls on ministries to consider climate impacts, where relevant, in service and business plans, projects, legislation, regulations, and approvals. The goal of the Strategy is that B.C. be prepared for unavoidable climate change and its impacts. Many of these potential climate impacts are directly relevant to government business.

In accordance with the BC Climate Change Adaptation Strategy, the BC Ministry of Transportation and Infrastructure considers potential climate change and impacts, in planning, projects, policies, legislation, regulations and approvals. Ministry areas affected include: Operational Programs (Transit, Cycling, Avalanche), Engineering Programs (design standards and guidelines), and Maintenance Programs (considerations based on climate predictions).

In response to potential climate issues, the Ministry of Transportation, Chief Engineer's Office, is engaged in case studies to examine climate risk to BC transportation infrastructure and what engineering adaptation is required for a 50 to100 year planning horizon. The Ministry is engaged with other national, provincial and academic organizations in developing experience and expertise in this field. To date our partners include: Engineers Canada (Public Infrastructure Engineering Vulnerability Committee - PIEVC), the Pacific Climate Impacts Consortium (PCIC) at the University of Victoria, and the BC Ministry of Environment.

Climate risk case studies have been completed for sections of the Coquihalla Highway 5 and Yellowhead Highway 16 in BC using the Climate Change Infrastructure Vulnerability Assessment Protocol (PIEVC). The results from examining forecast climate and infrastructure interactions including findings and recommendations and any required remedial action will be addressed. These studies assist the Ministry in planning for potential climate change.

The results from these studies of the Coquihalla and Yellowhead Highways will provide background guidance in reviewing design standards for highway infrastructure in British Columbia.

1 Introduction

British Columbia's public transportation infrastructure is vital to the social and economic wellbeing of the province. Therefore it needs to be designed, operated and maintained in a way that minimizes the risk of potential destruction, disruption or deterioration due to changing climatic conditions.

The engineering profession through Engineers Canada and the Public Infrastructure Engineering Vulnerability Committee (PIEVC) is working towards an understanding of climate change and how to account for it in design, rehabilitation, operation and maintenance of Canadian public infrastructure.

There is a need to determine adaptive capacity of public infrastructure within current policies and standards based on climate models if we are to provide relevant tools to guide Professional Engineers in their day-to-day practice.

PIEVC has produced a five-step protocol that has been used to assess climate change engineering vulnerability on over 20 infrastructure systems throughout Canada. In early 2010, BC MoTI applied this protocol in the evaluation of the climate change on a segment of the Coquihalla Highway. This work was reported at the TAC conference in Halifax in September 2010.

Additionally, in early 2011 a study using the PIEVC protocol has evaluating a segment of the Yellowhead Highway 16 in BC. These two studies form the basis of this paper.

2 Transportation Infrastructure in British Columbia

Transportation systems, particularly highway systems, are designed and constructed to withstand a wide range of climate conditions and events. Engineering design policy, standards and guidelines have been in place for many years to ensure the system can handle most anticipated climate conditions. Many of these policies, standards and guidelines have climate assumptions built into them.

These are usually derived from historic climate information and trends. Climate change is expected to change these trends and, as a result, climate assumptions built into current highway system engineering policies, standards and guidelines must be re-examined to ensure future climate trends are accounted for in design policies, standards and guidelines for works expected to last for the next 50 to 100 years.

British Columbia’s varied climate creates different conditions in different parts of the province that requires us to develop different, specific design criteria for each area. The same road or bridge will react very differently depending upon the climate zone that it’s in. So, there is already consideration of varying climate conditions incorporated into our design process. But these considerations are based on less than perfect historic climate data and information. Climate change will require us to re-examine the climate parameters incorporated into the design standards and guidelines.

3 Project Definition – Site Selection

In order to evaluate and compare transportation infrastructure in different regions of the province, potential sites that could be used in an assessment of roadway and associated infrastructure vulnerability due to climate change, Jennifer Hardy of BC MoTI developed site selection criteria and applied those criteria to eight potential project sites. Based on these criteria, the team then conducted a weighted decision analysis to rank the sites.

For the purposes of the site evaluation, the team selected potential sites that included a section of roadway covering approximately 30 km to 40 km.

For each potential site, the BC MoTI Team assigned a rating between 0 (poor) and 5 (excellent) for each criterion on the "Site Rating" spreadsheet. This rating indicated the degree to which the site was a good candidate based on those specific criteria.

Once a site had been rated, a score for the site was calculated based on the criteria weighting and the site ratings.

The overall scores for each section of highway are presented in **Figure 1**.

Figure 1
Preliminary Screening of Potential Sites

Site	Score
Hwy 3, Kootenay Pass (between Salmo and Creston)	129
Hwy 31, Meadow Creek to Trout Lake	126
Hwy 16, Burns Lake to Smithers	130
Hwy 29, Chetwynd to Charlie Lake	117
Hwy 14, Sooke to Port Renfrew	111
Hwy 5, Coquihalla (between Hope and Merritt)	154
Hwy 3, Paulson Pass (between Christina Lake and Junction with Hwy 3B)	119
Hwy 16, Terrace to Prince Rupert	149

Based on the analysis completed by the BC MoTI Team, the stretch of Coquihalla Highway between Hope and Merritt received the highest overall rank and was selected as the focus of the first infrastructure climate change vulnerability assessment conducted by BC MoTI. That assessment was completed in March 2010.

The second highest score was given to the stretch of Highway 16 between Terrace and Prince Rupert. However, BC MoTI concluded that that stretch of highway exhibited very similar climatic and geographical features to the Coquihalla Highway.

BC MoTI wished to demonstrate an application of the Protocol under different climatic and geographical conditions. Based on this assessment, BC MoTI selected B.C. Yellowhead Highway 16 to the east of the Smithers section, for the focus of this current assessment. Priestly Hill is just east of Burns Lake. For the purposes of this vulnerability assessment, this section of highway was designated ***Highway 16 between Vanderhoof and Priestly Hill***.

4 Study Considerations

4.1 Yellowhead Highway 16

Vanderhoof, about 100 km west of Prince George on Yellowhead Highway 16, is the geographic centre of British Columbia. Prince George has a population of over 70,000. It is the largest city in northern British Columbia and is known as the "BC's Northern Capital". Situated at the confluence of the Fraser and Nechako Rivers, and the crossroads of Highway 16 and Highway 97, the city plays an important role in the province's economy and culture.

Many activities have been associated with the area including fur trading, mining, farming, the railroad, lumber and mills.

The Yellowhead Highway in British Columbia runs from the eastern border with Alberta west through the Cariboo Mountains to Prince George, and through the Fraser Plateau, the Bulkley River Valley and the Skeena River Valley, before reaching the west coast at Prince Rupert. In 1942 the number '16' was assigned to the British Columbia portion of this road.

The Yellowhead Highway closely follows the path of the northern B.C. alignment of the Canadian National Railway and in 1947 the western end of the highway was moved from New Hazelton to the coastal city of Prince Rupert.

In the late 1960's and very early 1970's, Highway 16 was completed east from Prince George to the Yellowhead Pass (Tete Jaune Cache) with a series of construction and paving projects. If there was a link prior to 1970, it would have been not much more than a series of connected logging roads.

The original surfacing for Highway 16 west of Prince George is not well documented. It appears from the incomplete histograms that the first serious upgrading of the 155 km-long stretch between Prince George and Fraser Lake was carried out between 1953 and 1960 when 450 to 600 mm of pit run gravel was placed and then capped with a 75mm thick pulvi-mix (cold mix) pavement surface (the east 135 km) or a sealcoat surface (the west 20 km).

The pit run gravel was likely highly variable in quality and size, and it appears there is no identifiable processed (crushed) base course layer beneath the pavement. From 1960 to 1995, a number of pavement patches, pavement overlays (including asphalt base course mixes, recycled asphalt pavements, and conventional pavements), chip seals, sealcoats, and crack seals have been carried out. Pavement thicknesses range from 200mm to 450mm, with an average of about 300mm.

Although the pavement structures are highly variable throughout this stretch of road with largely unknown parameters for the structure components, the road surface is very strong and there are no observable or measurable strength deficiencies – largely due to the thick pavement. Consequently, rehabilitation work carried out over the last 15 years has mostly included hot-in-place recycling and sealcoat treatments to improve/preserve the existing surface rather than increase its thickness.

The location of the infrastructure is detailed in **Figure 2**.

4.2 Coquihalla Highway 5

The Hope to Merritt section of the Coquihalla Highway, Hwy 5, in British Columbia was constructed between 1982 and 1986 through mountainous terrain bordered by the Fraser Delta to the West and the Cascade Mountain Range to the East. In addition, the Coquihalla River and Boston Bar Creek alternate alongside the length of the highway with significant road elevation change of approx 900 m from the start point to the end point.

This assessment evaluated a 44.83km in length of highway from the Nicolum River Bridge, North End to the start of Dry Gulch Bridge.

The Coquihalla Highway is a 4 lane, divided, high-speed provincial roadway where the posted speed is 110 kph, maximum grade of 8% with climbing lanes and crawling lanes.

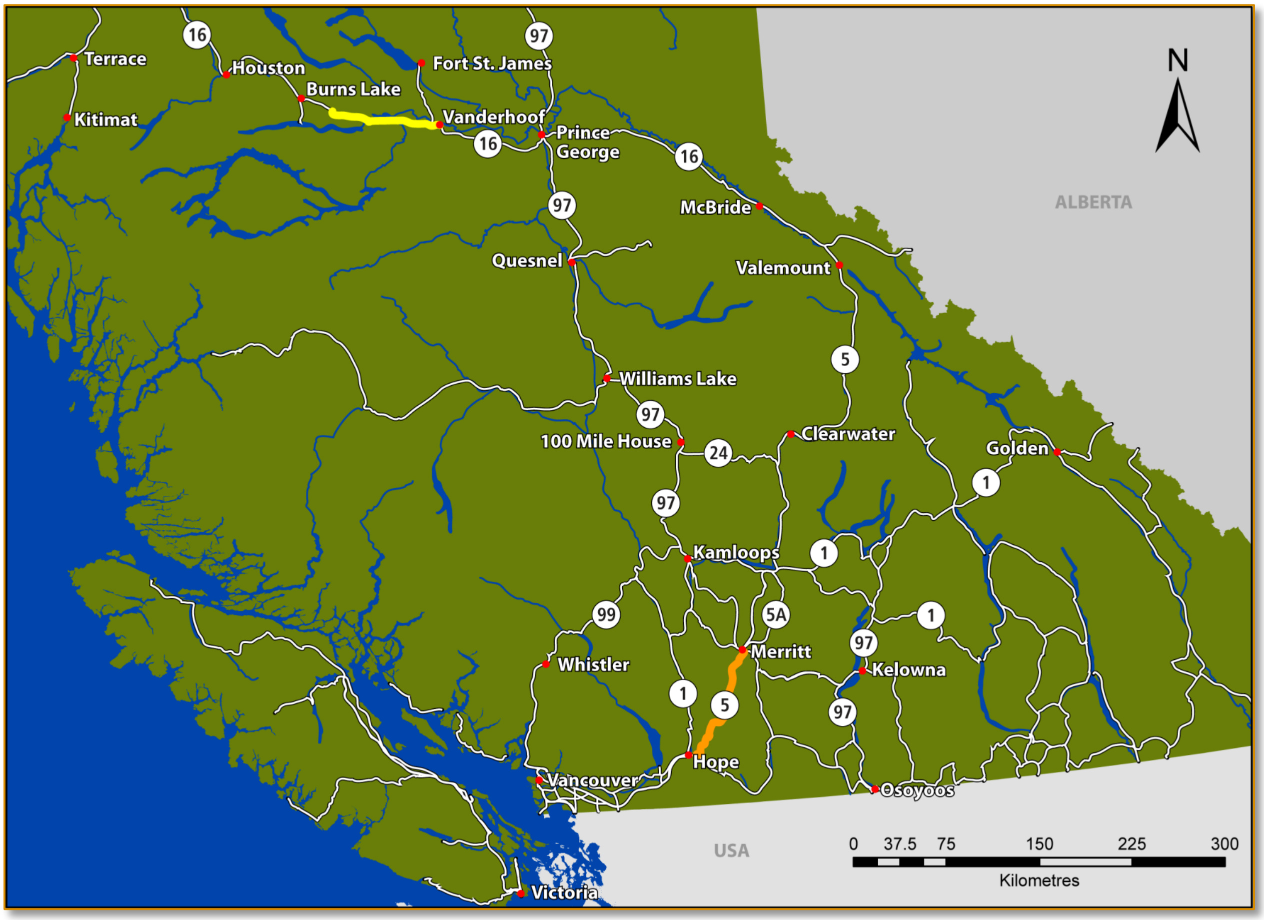
There is a significant road elevation change of approximately 900 meters from the study start point to the study end point.

The original surfacing structure generally consisted of 75 mm of asphalt concrete pavement over 300 mm of well graded base (19 to 75 mm max size) over 600 to 900 mm of select granular sub-base.

The majority of the pavements for the Coquihalla Highway have undergone some form of rehabilitation and maintenance since initial construction in the 1980s. Since construction, rehabilitation and maintenance activities have generally consisted of hot-in-place recycling, mill and fill of 50 to 100 mm of asphalt and concrete and chip sealing.

The location of the infrastructure is detailed in **Figure 2**.

Figure 2: Map of Infrastructure Locations



Yellowhead
The B.C. Section of the Yellowhead Highway runs from Alberta to the Pacific Ocean and was designated Highway 16 in 1942. The study section is on the Fraser Plateau in Central B.C.
Coquihalla
The Hope to Merritt section of the Coquihalla Highway, was constructed between 1982 and 1986 through mountainous terrain bordered by the Fraser Delta to the West and the Cascade Mountain Range to the East

4.3 Time Frame

The team identified one time horizon for the Coquihalla Highway (2050) and two for the Yellowhead Highway (2050, 2100) assessment.

This was based on the notional functional service life of the highway without significant rehabilitation work.

4.4 Climate Factors used in Yellowhead Highway Assessment

Using the Yellowhead Highway as an example, initially, the team identified an extensive list of potential climate factors. 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 **Figure 3**.

Figure 3: Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment (Yellowhead Hwy)

Climate Parameter	Infrastructure Indicator
High Temperature	Day(s) with maximum temperature exceeding 35°C
Low Temperature	Day(s) with minimum temperature below -35° C
Freeze / Thaw	Number of days where maximum temperature > 0° C and minimum temperature < 0° C
Frost / Frost Penetration	47 or more consecutive days where minimum temperature < 0° C
Total Annual Rainfall	406.7 mm
Extreme High Rainfall	> 35 mm rain
Sustained Rainfall	≥ 5 consecutive days with > 3.5 mm rain
Snow (Frequency)	Days with snow fall > 10 cm
Snow Storm / Blizzard	8 or more days with blowing snow
Rain on Snow	Period where rain falls on existing snowpack.
Hail / Sleet	Days with precipitation falling as ice particles
Rain on Frozen Ground	Precipitation > 6 mm/3h

Figure 3: Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment (Yellowhead Hwy)

Climate Parameter	Infrastructure Indicator
	No snowfall, Surface Temperature < 0 °C
High Wind / Downburst	≥ 8 days with Max winds ≥ 63 km/hr
Rapid Snow Melt	Snow melt > 9 mm/3h
Snow Driven Peak Flow Events	N/A
Ice / Ice Jams	N/A
Ground Freezing	Number of days below -5 ° C

4.5 Infrastructure Components Evaluated for the Yellowhead Highway

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.

The final infrastructure component listing used for this study is presented in **Figure 4**.

Figure 4: Infrastructure Component Listing

	Above Ground
1	Asphalt - Hot in Place
2	Asphalt - Seal Coat
3	Pavement Marking
4	Shoulders (Including Gravel)
5	Barriers
6	Curb - Concrete
7	Curb - Asphalt
8	Luminaires
9	Poles
10	Signs - Sheeting
11	Signs - Wood or metal bases
12	Signage - Side Mounted - Over 3.2 m^2
13	Signage - Overhead Guide Signs

Figure 4: Infrastructure Component Listing

14	Overhead Changeable Message Signs – Weigh Scale
15	Ditches
16	Embankments/Cuts
17	Natural Hillsides
18	Engineered Stabilization Works
19	Structures that Cross Streams - Bridges
20	Structures that Cross Roads - Bridges
21	Railways (Drainage Interaction)
22	River Training Works - Rip Rap
23	Retaining Walls - MSE Walls
24	Asphalt Spillway and Associated Piping – Above Ground Elements
Below Ground	
25	Pavement Structure
26	Catch Basins
27	Roadway Drainage Appliances
28	Sub-Drains
29	Below Ground Third Party Utilities
30	Above Ground Third Party Utilities
31	Culverts < 3m in diameter
32	Culverts ≥ 3m in diameter
33	Piping/Culvert - Below Ground Elements.
Miscellaneous	
35	Winter Maintenance
36	Habitat Features
37	Routine Maintenance
38	Pavement Marking Repair
39	Pavement / Curb/ Barrier / Sign Repair

5 Climate Change Considerations

Two approaches were used to establish the climate parameters used in the climate change risk assessment. These include:

1. Climate modeling; and
2. Sensitivity analysis.

5.1 Climate Modeling

The Pacific Climate Impacts Consortium (PCIC) provided climate modeling for the study. PCIC's provided three model evaluations for the Coquihalla Highway study and five in the Yellowhead Highway.

PCIC used five GCMs to project future global climatic conditions, and five RCMs to obtain regional estimates for the area of the Yellowhead Highway. The RCM/GCM parings used in this study are the:

1. Canadian Regional Climate Model (CRCM)
   - Driven by the Third Generation Global Coupled Climate Model (CGCM3)

2. Hadley Centre Regional Climate Model (HRM3)
   - Driven by the Hadley Centre Coupled Model, Version 3 (HadCM3)

3. ICTP Regional Climate Model (RCM3)
   - Driven by the Geophysical Fluid Dynamics Laboratory Global Climate Model (GFDL)

4. ICTP Regional Climate Model (RCM3)
   - Driven by the Third Generation Global Coupled Climate Model (CGCM3)

5. Iowa State University MM5 – PSU/NCAR Mesoscale Model (MM5I)
   - Driven by National Centre for Atmospheric Research - Community Climate System Model (CCSM)

6. Weather Research and Forecasting Model (WRFG)
   - Driven by National Centre for Atmospheric Research - Community Climate System Model (CCSM)

GCMs are based on assumed greenhouse gas emission scenarios, developed by the Intergovernmental Panel on Climate Change (IPCC). For the purposes of this study, PCIC used the following emissions scenarios: 20C3M (Present), A1B and A2. Examples of the themes of the A1B model are below.

A1B

This scenario represents a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are:

- A more integrated world;
- Rapid economic growth;
- A global population that reaches 9 billion in 2050 and then gradually declines;
- The quick spread of new and efficient technologies;
- A convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide; and
- A balanced emphasis on all energy sources.

Yellowhead Climate Forecast (2050, 2100)

- Regionalized (dynamical and statistical) climate projections - Yellowhead Hwy section indicate

- warmer conditions
  - decreasing strong frost periods (very likely)
  - increasing hot extremes (very likely)
  - decreasing diurnal temperature range (very likely)
- wetter conditions
  - total precipitation increasing (likely)
  - heavier and more sustained precipitation (likely)
- more extreme conditions
  - moderate (10y) to extreme (>100y) events increasing

Coquihalla Climate Forecast (2050)

- Climate projections for Coquihalla Hwy section:
  - Warming with
    - Increasing hot extremes
    - Decreasing periods of hard frost
  - Reduction in the range of temperatures; and
  - An increase in periods of heavy precipitation (requiring more detailed empirical downscaling to resolve)

5.2 Risk Ranking

$$R = P \times S$$

Where:

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

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. BC MoTI confirmed their acceptance of the risk thresholds defined by the Protocol for application in this process.

Figure 7 outlines the risk thresholds used for this risk assessment.

Figure 7: Historic Risk Tolerance Thresholds and Colour 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 team ranked risks into three categories:

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

Yellowhead Highway Risk Assessment

The team originally conducted the risk assessment on 178 potential climate-infrastructure interactions. Based on the analysis the team identified:

- 137 interactions with low or no material risk;
- 41 interactions with medium risk; and
- No interactions with high risk.

Of the 41 medium level risks, most were relatively minor with 26 interactions generating risk scores in the range 12 to 18. Only 15 interactions generated risk scores in excess of 18 and there were no risk scores in excess of 25.

Coquihalla Highway Risk Assessment

The team originally conducted the risk assessment on 560 potential climate-infrastructure interactions. Based on the analysis the team identified:

- 435 interactions with low or no material risk;
- 111 interactions with medium risk; and
- 14 interactions with high risk.

Of the 111 medium level risks, the majority were relatively minor with risk scores in the range 12 to 18.

All 14 high level risks were associated with heavy rainfall and Pineapple Express climatic events. In fact, in these categories even the medium risk items scored quite high - generally greater than 18 and often higher than 30. Thus, these climatic events are responsible for all of the high risk and high-medium risk climate-infrastructure interactions.

The sensitivity analysis did not materially change these results.

Decreasing the probability of Pineapple Express events resulted in fewer high-risk scores. However, close review of these scores indicated that they were still very high-medium risk items – generally greater than 24 and frequently greater than 30. That is, although these items shifted from high to medium risk based on the coarse scaling suggested by the Protocol, they nonetheless remained relatively serious risks.

Although increasing the probability of rain on snow, freezing rain and snow accumulation increased the risk scores; none of the identified medium level risks were escalated to the high-risk category. Some items did rise to relatively high medium-risk values but none of these values exceeded a risk score of 30. Thus, this sensitivity analysis generally supported the overall risk profile determined at the workshop.

Figure 8
Summary of Climate Change Risk Assessment Scores for the Yellowhead Highway

Infrastructure Components	High Temperature	Low Temperature	Freeze/Thaw	Total Annual Rainfall	Extreme High Rainfall	Sustained Rainfall	Snow (Frequency)	Rain on Snow	Hail / Sleet	Rain on Frozen Ground	High Wind/ Downburst	Rapid Snow Melt	Snowmelt Driven Peak Flow Events (Spring Freshet)	Ice / Ice Jams	Ground Freezing
Above Ground															
Asphalt - Hot in Place	18	0	5												12
Asphalt - Seal Coat	6	0	5												12
Pavement Marking	0	0	5												
Shoulders (Including Gravel)	0		5		20	15									
Barriers					10										
Curb - Concrete			10		10										
Curb - Asphalt	0	0	5		10										
Luminaires										0	0				
Poles										0	2				
Signs - Sheeting											0				
Signs - Wood or metal bases										0	0				
Signage - Side Mounted - Over 3.2 m^2										0	4				
Signage - Overhead Guide Signs										0	4				
Overhead Changeable Message Signs - Weigh Scale										0	4				
Ditches			0	10	20	5		8				12			
Embankments/Cuts	0		5	10	20	15		8				16			
Natural Hillsides	0		5	10	10	10		8				12			
Engineered Stabilization Works															
Structures that Cross Streams - Bridges	24	6	15	10	15	10		8		3	0	4	15	6	
Structures that Cross Roads - Bridges	24	6	15		15	10		8		3	0				
Railways (Drainage Interaction)				10	10	10		8		0		8	10		
River Training Works - Rip Rap				10	15	10						4	15	6	
Retaining Walls - MSE Walls															
Asphalt Spillway and Associated Piping - Above Ground Elements	0		10	10	25	10		12		3		8			
Below Ground															
Pavement Structure			5	10		10									6
Catch Basins			10	5	25	10		12	0	6		8			
Roadway Drainage Appliances			10	5	25	10		12	0	6		8			
Sub-Drains		0	5	5	10	10		4							
Below Ground Third Party Utilities					10					0					
Above Ground Third Party Utilities										6					
Culverts < 3m		0	5	5	25	15		12	3			16	25	9	
Culverts ≥ 3m		0	5	5	15	10		4				4	20	9	
Piping/Culvert - Below Ground Elements.			5	5	20	10		12				8			
Miscellaneous															
Winter Maintenance		6	20		20		2	16		15	4	4		9	
Habitat Features															
Routine Maintenance	6	6	15		25	10				3	4	8			
Pavement Marking Repair							0								
Pavement / Curb/ Barrier / Sign Repair							2								

6 Vulnerability Evaluation

In this step the team assessed the impact of projected climate change loads for four climate-infrastructure combinations:

1. Road Surfaces (Coquihalla)
2. Median & Roadway Drainage Appliances (Coquihalla)
3. Catch Basins & 24-hour Duration Extreme Rainfall (Coquihalla/Yellowhead)
4. Culverts < 3 m & 24-hour Duration Extreme Rainfall (Yellowhead)
5. Concrete Bridges & Extreme High Temperature (Yellowhead)
6. Concrete Bridges & Extreme Low Temperature (Yellowhead)

Vulnerability exists when infrastructure has insufficient capacity to withstand the projected or anticipated loads that may be placed on it. Resiliency exists when the infrastructure has sufficient capacity to withstand increasing loads resulting from climate change.

Engineering Analysis requires the assessment of the various factors that affect load and capacity of the infrastructure. Based on this assessment, indicators or factors are determined in order to relatively rank the potential vulnerability of the infrastructure elements to various climate effects.

Much of the data required for Engineering Analysis may not exist or may be very difficult to acquire. Engineering Analysis requires the application of multi-disciplinary professional judgment. The results of the analysis yield a set of parameters that can be ranked relative to each other, based on the professional judgment of the team. This can be used to rank the relative vulnerability or resiliency of the infrastructure.

BC MoTI formed a small sub-committee of the team to focus on this activity. The work was completed subsequent to the workshop over the period January 20, 2011 through February 11, 2011.

The results from the vulnerability evaluation are presented in **Figure 9**.

Figure 9: Vulnerability

Infrastructure Component	Design Standard	Total Load	Total Capacity	Vulnerability
	Return period Max-min temp	L_T	C_T	$V_R = \frac{L_T}{C_T}$
Road Surfaces & 24-hrs Duration Extreme Rainfall (mm/24hrs)	**1:5**			
Coquihalla 2050s		101	88	1.15
Median & Roadway Drainage Appliances & 24-hrs Duration Extreme Rainfall (mm/24hrs)	**1:10 to 1:25 (use 1:25)**			
Coquihalla 2050s		153	121	1.26
Catch Basins & 24-hrs Duration Extreme				

Figure 9: Vulnerability

Infrastructure Component	Design Standard	Total Load	Total Capacity	Vulnerability
	Return period Max-min temp	L_T	C_T	$V_R = \frac{L_T}{C_T}$
Rainfall (mm/24hrs)				
Coquihalla (Storm Sewers) 2050s	**1:10 to 1:25 (use 1:25)**	139	117	1.19
Yellowhead 2050s	**1:5**	33.8	27.8	1.21
Yellowhead 2100s	**1:5**	41.4	27.8	1.49
Culverts < 3 m & 24-hour Duration Extreme Rainfall (mm/24hrs)	**1:100**			
Yellowhead 2050s		56.6	42.8	1.32
Yellowhead 2100s		73.8	42.8	1.73
Concrete Bridges & Extreme High Temperature (^{o}C)	**Max-min temp (Forecast event 1:50)**			
Yellowhead 2050s		35.7	34.4	1.04
Yellowhead 2100s		37.5	34.4	1.09
Concrete Bridges & Extreme Low Temperature (^{o}C)	**Max-min temp (Forecast event 1:50)**			
Yellowhead 2050s		-48.8	-45.0	1.08
Yellowhead 2100s		-53.4	-45.0	1.19

6.1 Discussion

Coquihalla Vulnerability

The results of the engineering analysis supported the conclusions reached through the risk assessment. The team concluded that high intensity rainfall events could overload drainage infrastructure. Specifically:

- Water on roadway surfaces could impede traffic;
- Maintenance effects could include increased erosion; and
- Environmental effects of increased erosion include carrying sediments and contaminants to watercourses.

Based on these considerations the team concluded that increased rainfall intensity could require updated policies and procedures regarding design and maintenance of highway infrastructure.

Yellowhead Vulnerability

Road

Road pavement asphalt cement (AC) oil grade has traditionally been chosen from historical high and low temperature ranges for the location where the highway is situated. In our study section of the Yellowhead highway, the pavement AC grade currently used is a 150/200-penetration grade, which is the equivalent to a PG 58-31 performance grade. This AC grade has a pavement surface temperature range from +58°C to -31°C.

According to climate records, the lowest air temperature in Vanderhoof was in 1984 and was -47°C. However, this was air temperature and not surface temperature and may have occurred for only one day or part of one day. Therefore, this extreme low air temperature may not have decreased the surface road temperature below its design low range of -31°C. As well, the forecast climate tells us that the low temperatures will moderate and thus less severe cold temperatures are expected in the future.

Bridge

For concrete bridges in the study area, higher forecast future temperatures present a slight vulnerability based on the calculations that we assume were used when these bridges were built and the forecast temperatures developed in this study. This would be negligible on the superstructure; however it may be prudent to monitor the bearings and expansion joints during extreme temperature events.

For lower temperatures, the design standard range indicated for the Vanderhoof area is -45°C for concrete bridges, and -55°C for steel bridge structures. The most severe future forecast low temperature for 50y return is -49°C and for 200y is -55°C. So, slight design vulnerability may exist for concrete bridges according to this analysis. However, the present observed low temperature values that are perhaps skewed by the -47°C temperature of 1984, indicate a vulnerability currently: i.e. 50-year return of -55°C and 200-year return of -62°C.

Moderating these potential vulnerabilities and capacity deficits is the lag between air temperature and the interior temperature of massive concrete members or structures. While future forecast temperatures might indicate slight vulnerability in the design temperature range of bridges, extreme high or low temperatures rarely affect the structural integrity of bridges, even outside the design specification - especially over short periods.

Culverts < 3 Metres

Further analysis on the vulnerability of culverts < 3m is recommended due to the uncertainties in the climate models and lack of survey information. At critical locations, it may be necessary to do a detail assessment based on the watershed settings and site conditions. Nevertheless this analysis indicates that some culverts in the area may not meet the Ministry Standard with future increased load.

6.2 Comparison: Yellowhead and Coquihalla Highway Vulnerability Assessments

- Different terrain
  - Coquihalla mountainous area 900m change in elevation
  - Yellowhead on interior plateau

- Different climate
  - Coquihalla – extreme rainfall: Pineapple Express (PE)
  - Yellowhead – long cold winters, short hot summer

- Similar results with higher precipitation
    - Future forecast extreme rainfall on Coquihalla (from PE) and Yellowhead cause existing structures to be vulnerable as designed (using historical climate data)

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

The particular section of Yellowhead Highway was selected for this assessment because of the significant differences between the two highway infrastructures' geographic and climatological locations.

The Coquihalla Highway is located in mountainous terrain. The Coquihalla River or tributaries run alongside the length of the highway infrastructure with a significant road elevation change of approximately 900 meters from the start point to the end point. There is significant climatological gradient, especially at the top end of this section of road. This can lead to dramatic differences in the climatic conditions experienced over a few kilometres of the highway.

In contrast, the Yellowhead Highway runs from the eastern border with Alberta west through the Cariboo Mountains to Prince George, and through the Fraser Plateau, the Bulkley River Valley and the Skeena River Valley, before reaching the west coast at Prince Rupert. There is no significant climatological gradient in the region of the study, the area being generally in a plateau region.

The Coquihalla Highway is more exposed to Pacific weather systems, such as the Pineapple Express, which played a significant role in the overall risk profile. The highway was found to be very sensitive to drainage issues and exhibited a large number of high-risk interactions related to extreme rainfall events.

The climate in the region of the Yellowhead highway is somewhat attenuated by its inland location. As a result, the infrastructure risk profile presents a lower level of overall risk, with no identified high-risk interactions. Nonetheless, the highway did exhibit sensitivity to anticipated higher levels of rainfall resulting in some heightened risk associated with highway drainage.

Although the risk profile for the Yellowhead Highway was determined to be lower than the Coquihalla Highway, the issues that drive the risk were found to be quite similar – higher overall anticipated levels of precipitation.

6.3 Highway Climate Change Vulnerability

Based on these risk assessments, the Yellowhead and Coquihalla Highways are generally resilient to climate change with the exception of drainage infrastructure response to extreme rainfall events.

7 Conclusion

Recent studies on climate risk and infrastructure impacts in British Columbia indicate the importance of considering the lifespan of highway structural components and site/terrain characteristics when evaluating climate risk scenarios at individual locations in the process of reviewing highway design criteria.

Highway components are designed for various working timeframes (10 years, 15 years, 50 years, etc.): for example, pavement is generally rehabilitated within 15-20 years and bridges have a working life of 50+ years.

The Yellowhead and Coquihalla studies forecast climate risk 40-50 years into the future, and the Yellowhead study included a 100-year climate risk outlook. These forecasts help in shaping the context for reviewing, developing and adopting future highway design criteria.

The studies identified potential issues around design specifications based on historical climate data rather than future climate scenarios at specific geographic locations. Ideally, design considerations would account for future climate conditions and site/terrain influences as well as product specifications and changes in achieving the best design and product performance.

With this in mind, the studies point to potential future changes in climate and therefore warrant reviewing highway infrastructure design specifications of certain components such as: asphalt cement grades; temperature sensitive components of bridges; and drainage design based on increased precipitation in many areas of the province of British Columbia.