Executive Summary

Climate Change Engineering Vulnerability Assessment

B.C. Yellowhead Highway 16
Between Vanderhoof and Priestly Hill

Rev 3
March 27, 2011

1 Introduction

The Ministry of Transportation and Infrastructure, Province of British Columbia (BC MoTI) worked with Engineers Canada and the PIEVC to assess the engineering vulnerability of a stretch of B.C. Highway 16 between Vanderhoof and Priestly Hill.

The principle objective of this case study was to identify those components of the Yellowhead Highway 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 nature and relative levels of risk were determined in order to establish priorities for remedial action.

The assessment was carried out using the ***PIEVC Engineering Protocol, Version 9, April 2009.***

This project was completed over the period October 1, 2010 through February 28, 2011 and contemplated climate change effects for two climate change projection horizons – 2050 and 2080.

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 the Yellowhead project, the primary technical and operations infrastructure knowledge was provided by BC MoTI personnel, who managed and drove the project and were responsible for identifying and assessing the likely response of the infrastructure to projected climate change.

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

2 Project Definition

In order to evaluate and compare potential sites that could be used in an assessment of roadway and associated infrastructure vulnerability due to climate change, 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. 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.

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 roughly between Burns Lake and Smithers for the focus of this current assessment.

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.

2.1 Climate Factors

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 A**.

Figure A: Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator
1	High Temperature	Day(s) with maximum temperature exceeding 35°C
2	Low Temperature	Day(s) with minimum temperature below -35° C
3	Average Temperature	Average Maximum Temperature Over 7 Days
4	Temperature Variability	Daily temperature variation of more than 25 ° C
5	Freeze / Thaw	85 or more days where maximum temperature > 0° C and minimum temperature < 0° C
6	Frost / Frost Penetration	47 or more consecutive days where minimum temperature < 0° C
7	Total Annual Rainfall	406.7 mm
8	Extreme High Rainfall	> 35 mm rain
9	Sustained Rainfall	≥ 5 consecutive days with > 25 mm rain
10	Longer Sustained Rainfall	≥ 23 consecutive days with > 10 mm rain
11	Low Rainfall	≥ 10 consecutive days with precipitation < 0.2 mm
12	Prolonged Dry Periods (Drought)	≥ 112 consecutive days with precipitation < 0.2 mm
13	Snow (Frequency)	Days with snow fall > 10 cm
14	Snow Accumulation	5 or more consecutive days with a snow depth > 60 cm
15	Snow Storm / Blizzard	8 or more days with blowing snow
16	Rain / Snow / Wind	Rain on snow including temperature and wind speed
17	Rain on Snow	10 or more consecutive days with rain on snow
18	Hail / Sleet	Days with precipitation falling as ice particles
19	Rain on Frozen Ground	Precipitation > 6 mm/3h
20	Freezing Rain	9 or more days with rain that falls as liquid and freezes on contact
21	Visibility	≥ 15 hours per year with visibility < 1,000 m
22	High Wind / Downburst	≥ 8 days with Max winds ≥ 63 km/hr

Figure A: Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator
23	Rapid Snow Melt	Snow melt > 9 mm/3h
24	Snow Driven Peak Flow Events	N/A
25	Ice / Ice Jams	N/A
26	Ground Freezing	Number of days below -5 ^{o} C

2.2 Time Frame

The team identified two time horizons for the assessment:

- To the year 2050; and
- To the year 2100.

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

2.3 Infrastructure Components

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 B**.

Figure B: 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

Figure B: Infrastructure Component Listing

12	Signage - Side Mounted - Over 3.2 m^2
13	Signage - Overhead Guide Signs
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
32	Culverts ≥ 3m
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

3 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.

3.1 Climate Modeling

The Pacific Climate Impacts Consortium (PCIC) provided climate modeling for the study. 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)

PCIC used statistical downscaling and probabilistic analysis to tailor the RCM outputs to local conditions in the region. The approach involves:

PCIC also reviewed historic weather conditions in the region through weather data retrieved from Environment Canada weather satiations dispersed throughout the region to rationalize results from the RCMs so that there is a meaningful correlation between observed and predicted climatic conditions in the study area.

The results from the PCIC work can be summarized, as follows.

- The number of frost days will decline sharply from about 200 to approximately 150 by the year 2100
- The number of ice days will decrease.
- The growing season length will increase from roughly 170 days to nearly 200 days by the end of the century.
- Precipitation totals may increase from 500 mm to about 600 mm.
- There will be more extreme weather events, overall.
- The portion of days where the maximum temperature is above the present-day median will increase from 50% to almost 80% by the end of the century
- The annual minimum temperature will increase from -25°C to -20°C by 2100.
- Annual maximum temperature values, which are presently safely below the 35°C mark relevant to bride and highway design, will start to cross this line by mid century and even approach and exceed 40°C by the end of the century.

4 Risk Assessment Workshop

The Risk Assessment workshop was conducted over a two-day period on January 18 and 19, 2011. The team used this workshop to carry out the analysis defined by Step 3 of the Protocol.

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

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

Figure C: 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

4.2 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.

Based on the probability and severity scores, the team calculated the risk outcomes using the equation:

$$R = P \times S$$

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 defined risk tolerances and color-coded, as indicated in **Figure C.**

The calculated risk scores arising from this assessment are presented in **Figure D**.

4.3 Risks Ranking

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 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.

5 Vulnerability Evaluation

Based on calculations of total load and total capacity, the team calculated the vulnerability ratios for four interactions. The infrastructure component is deemed to be vulnerable when $V_R > 1$. That is, the projected load is greater than the projected capacity. The infrastructure component is deemed to be resilient when $V_R < 1$. The results from the vulnerability evaluation are presented in **Figure E**.

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.

Figure D: Summary of Climate Change Risk Assessment Scores

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								

Figure E: Vulnerability

Infrastructure Component	Total Load	Total Capacity	Vulnerability
	L_T	C_T	$V_R = \frac{L_T}{C_T}$
Catch Basins & Extreme Rainfall over 24 Hours (mm)			
2050s	33.8	27.8	1.21
2100s	41.4	27.8	1.49
Culverts < 3 m & 24-hour Duration Extreme Rainfall (mm/24hr)			
2050s	56.6	42.8	1.32
2100s	73.8	42.8	1.73
Concrete Bridges & Extreme High Temperature (^oC)			
2050s	35.7	34.4	1.04
2100s	37.5	34.4	1.09
Concrete Bridges & Extreme Low Temperature (^oC)			
2050s	-48.8	-45.0	1.08
2100s	-53.4	-45.0	1.19

6 Recommendations

1. BC MoTI should investigate current design reserve capacity of the Yellowhead Highway 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 if University of British Columbia (or other) infrastructure failure models contemplate climate as a variable and if this can be adapted to BC MoTI's needs.

5. Develop relevant, practical design parameters and guidelines to help designers account for the future influence of climate change on highway infrastructure designs. For example, 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 linear relationship. Future hydrotechnical design may require more complex engineering such as continuous rainfall analysis and watershed modeling.

6. 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.

7. Further assessment is recommended for the Ross Creek culvert to determine if upgrade or retrofit will be required even to handle the existing load.

8. BC MoTI should monitor the impact of extreme high temperature on concrete bridge structures.

9. There appears to be no immediate need for action on this matter. However, should ongoing monitoring indicate a potential problem, BC MoTI should initiate a detailed engineering study of this matter.

10. BC MoTI should evaluate pavement grade design and bridge design standards. It would be useful to consider future forecast climate (temperatures) for the lifespan of the structure, rather than rely on historical climate parameters such as minimum and maximum mean daily temperatures as is currently used.

11. Although the team concluded that the results generated by the sensitivity analysis are relatively robust, through more advanced statistical downscaling work, BC MoTI should pursue better definition of Ice and Ice Jams

12. BC MoTI should conduct more study into visibility issues to define how these issues arise currently on the highway.

13. Once BC MoTI has developed a better definition of current visibility issues, they should assess the impact of climate change on this matter.

14. BC MoTI should establish central repositories for technical, engineering, design, operation and climatic data necessary to conducting climate change vulnerability assessments for each highway segment contemplated for future vulnerability assessment studies.

7 Closing Remarks

7.1 Adaptive Management Process

BC MoTII initiated this study as the second phase of an ongoing climate change adaptive management process. Through this study BC MoTI:

- Assessed the climate change vulnerability of the Yellowhead Highway;
- Developed an understanding of their climate data needs to facilitate future assessments on this, and other, BC MoTI infrastructure;
- Refined an infrastructure component list suitable for application on other BC MoTI highway vulnerability assessments;
- Refined skills and expertise in using the PIEVC assessment process;
- Identified a number of climate parameters for further study and assessment; and
- Developed a solid foundation for further vulnerability assessments on other infrastructure.

7.2 Yellowhead Highway Climate Change Vulnerability

Based on this risk assessment, the Yellowhead Highway is generally resilient to climate change with the exception of drainage infrastructure response to potential high rainfall events.