Climate Change Engineering Vulnerability Assessment of Transportation Infrastructure in British Columbia

by

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Abstract

The principle objective of this case study is to identify those components of the Hwy 5 between Hope and Coquihalla Lakes that are at risk of failure, damage and/or deterioration from extreme climatic events or significant changes to baseline climate design values.

The nature and relative levels of risk are to be determined in order to establish priorities for remedial action. The assessment shall be carried out using the PIEVC Engineering Protocol, Version 9 dated April 2009.

The scope of the assessment encompasses the current design, construction, operation and management of this infrastructure as well as any planned upgrades or major rehabilitation project in the planning stages.

The study is set to address potential impacts of climate change predictions on drainage and culverts under 3 meters out to 2050.

The results of this case study will be incorporated into a national knowledge base and analyzed with other case studies to develop recommendations around reviews of codes, standards and engineering practices.

1 Introduction

British Columbia's public transportation infrastructure is vital to the economic health of the province. Therefore it needs to be designed, operated and maintained in a way that minimizes the risk of 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 was evaluated through 7 case studies throughout Canada. In early 2010, BCMoTI applied this protocol in the evaluation of the climate change on a segment of the Coquihalla Highway. In this paper we discuss the climate change vulnerability assessment conduced by the British Columbia Ministry of Transportation and Infrastructure (BCMoTI) on the Coquihalla Highway and the ongoing plans that we have for evaluating the impact of climate change on B.C.'s highway system.

2 Transportation Infrastructure in British Columbia

Transportation systems, particularly highway systems, are design 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 requires us to re-examine the climate parameters incorporated into the design standards and guidelines.

3 Activities to Date

In 2008 BCMoTI engaged in a number of activities to examine the impact of climate change on B.C.'s highway system. At that time several workshops helped BCMoTI identify issues and form strategies and contacts to study the effects of climate change on BC's transportation infrastructure. From these interactions, climate scientists, consultants as well as internal staff teams were assembled for a climate change adaptation pilot project. This study completed in 2010 fits into the mandate of the recently released BC Climate Action Plan as it develops applied research to understand, prepare for and adapt to climate change in BC.

The question to be answered by this and other studies of its nature - is how will climate change affect our existing infrastructure and what steps will need to be taken to ensure new, future infrastructure will have adequate climatic resilience?

For the current study, BCMoTI worked with Engineers Canada and the PIEVC to assess the engineering vulnerability of an area approximately 44.83km in length of the Coquihalla Highway. The assessment was carried out using the ***PIEVC Engineering Protocol, Version 9, April 2009.***

The principle objective of this case study was to identify those components of the 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.

This project was completed over the period November 1, 2009 through March 31, 2010 and contemplated climate change effects through the year 2050.

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 Coquihalla project, the primary technical and operations infrastructure knowledge was provided by BCMoTI 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.

4 Project Definition – Site Selection

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, Jennifer Hardy of BCMoTI 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. Upon completion of this analysis, BCMoTI identified the Coquihalla Highway as the highest priority for this pilot study.

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 BCMoTI 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 BCMoTI 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 BCMoTI.

5 Study Considerations

5.1 *Coquihalla Highway*

Situated in south western British Columbia, the Coquihalla Highway is a key route connecting the Okanagan Valley and the West Coast. There is a wide range of climate from wet and temperate coastal conditions to dryer extremes in the interior region. On average, Hope receives 1,520 mm of precipitation per year, while Merritt receives only 300 mm.

In some locations average precipitation changes from 1,010 mm per year to 410 mm over 24 km distance. On rare occasions know as Pineapple Express events 150 mm of precipitation in 24 hrs has been reported. Coquihalla Valley has experienced 12 m (sometimes 15 m) of snow accumulation between October and May. As a consequence some areas are prone to avalanches

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.

The study focused on a 44.83 km stretch of road on Highway 5 between Nicolum River (sometimes referred to as Creek) Bridge north abutment at km .90 and the south abutment of Dry Gulch Bridge at 45.73 km.

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

The location of the infrastructure is detailed in **Figures 2 and 3**.

Figure 2
Map of Infrastructure Location

Figure 3
Close-up Map of Infrastructure Location

5.2 *Time Frame*

The team identified a time frame for the assessment of roughly 43 years – to the year 2053. This was based on the remaining useful service life of the highway without significant rehabilitation work.

5.3 *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 4**.

Figure 4 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator
1	High Temperature	Number of Days with max. temp. exceeding 30^{o} C
2	Low Temperature	Days with min. temp. below -24^{o} C
3	Temperature Variability	Daily temperature variation of more than 24^{o} C
4	Freeze / Thaw	17 or more days where max. temp. > 0^{o} C and min. temp.<0^{o} C

Figure 4 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator
5	Frost Penetration	Assessed through empirical analysis of forecast climate conditions.
6	Frost	47 or more days where min. temp. <0° C
7	Extreme Rainfall Intensity Over One Day	Determined empirically. PCIC used > 76mm over 24hrs.
8	Magnitude of Severe Storm Driven Peak Flows	Determined empirically. PCIC used directional wind speed, temperature and precipitation all > median values.
9	Frequency of Severe Storm Driven Peak Flow Events	Determined empirically. PCIC used directional wind speed, temperature and precipitation all > median values for three consecutive days in autumn.
10	Rain on Snow	10 or more days where rain falls on snow
11	Freezing Rain	1 or more days with rain that falls as liquid and freezes on contact
12	Snow Storm / Blizzard	8 or more days with blowing snow
13	Snow (Frequency)	Days with snowfall >10 cm
14	Snow Accumulation	5 or more days with a snow depth >20 cm
15	High Wind / Downburst	Wind speed > 80.5 km/hr
16	Visibility	Decrease in stopping sight distance < 245 m

5.4 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 5**.

Figure 5 Infrastructure Component Listing

Infrastructure Components	
#	**Infrastructure**
1	Surface - Asphalt
2	Pavement Marking
3	Shoulders (Including Gravel)
4	Barriers
5	Curb
6	Luminaires

Figure 5 Infrastructure Component Listing

	Infrastructure Components
7	Poles
8	Signage - Side Mounted - Over 3.2 m2
9	Signage - Overhead Guide Signs
10	Overhead Changeable Message Signs
11	Ditches
12	Embankments/Cuts (Constructed)
13	Hillsides (Natural)
14	Engineered Stabilization Works
15	Avalanche (Inc Protective Works)
16	Debris Torrents (Inc Protective Works)
17	Structures that Cross Streams
18	Structures that Cross Roads
19	River Training Works (Rip Rap)
20	MSE Walls
21	Pavement Structure above Sub-Grade
22	Catch Basins
23	Median and Roadway Drainage Appliances
24	Sub-Drains
25	Third party utilities
26	Culverts < 3m
27	Culverts ≥ 3m
28	Asphalt Spillway and Associated Piping/Culvert
	Environmental Features
29	In stream habitat works
30	Off channel habitat works
31	Wild life fence system
32	Wild life crossing structures
33	Vegetation management
34	Invasive Plants & Pests
	Miscellaneous
35	Administration/Personnel & Engineering
36	Winter Maintenance
37	Ancillary buildings and utilities and yards.
38	Communication
39	Emergency Response
40	Maintenance (Markings, Crack Sealing)

5.5 *Risk Assessment Methodology*

Based on the Protocol, the team developed a risk value for each of the climate-infrastructure interactions identified. 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.

Based on the protocol, the team selected the scale definitions for probability and severity that were applied consistently through the risk assessment process. **Figure 6** presents the probability scaling definitions that were applied by the team. **Figure 7** 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.

Figure 6
Probability Scale Factors

Scale	Probability*		
	Method A	Method B	Method C
0	negligible or not applicable	<0.1 % <0.1 / 20	negligible or not applicable
1	improbable / highly unlikely	5 % 1 / 20	improbable 1:1 000 000
2	remote	20 % 4 / 20	remote 1:100 000
3	occasional	35 % 7 / 20	occasional 1:10 000
4	moderate / possible	50 % 10 / 20	moderate 1:1 000
5	often	65 % 13 / 20	probable 1:100
6	probable	80 % 16 / 20	frequent 1:10
7	certain / highly probable	>95 % >19 / 20	continuous 1:1

Figure 7

Severity Scale Factors

Scale	Magnitude	Severity of Consequences and Effects
	Method D	Method E
0	no effect	negligible or not applicable
1	measurable 0.0125	very low / unlikely / rare / measurable change
2	minor 0.025	low / seldom / marginal / change in serviceability
3	moderate 0.050	occasional loss of some capability
4	major 0.100	moderate loss of some capacity
5	serious 0.200	likely regular / loss of capacity and loss of some function
6	hazardous 0.400	major / likely / critical / loss of function
7	catastrophic 0.800	extreme/ frequent/ continuous /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

5.6 *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. BCMoTI confirmed their acceptance of the risk thresholds defined by the Protocol for application in this process.

Figure 8 outlines the risk thresholds used for this risk assessment.

Figure 8

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

6 Climate Change Considerations

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

1. Climate modeling;
2. Synoptic analysis (the study of observations based on synoptic, or large-scale, weather charts based on the available data and professional expertise of the practitioner); and
3. Sensitivity analysis.

6.1 *Climate Modeling*

Climate modeling for the study was provided by the Pacific Climate Impacts Consortium (PCIC). PCIC used three regional climate models (RCMs) to project future climatic conditions:

- Canadian Regional Climate Model (CRCM)
- Hadley Centre Regional Climate Model (HRM3)
- ICTP Regional Climate Model (RCM3)

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

- Synoptic analysis of larger scale weather systems and how they affect local conditions;
- Statistical (regression) analysis; and
- Interpolation.

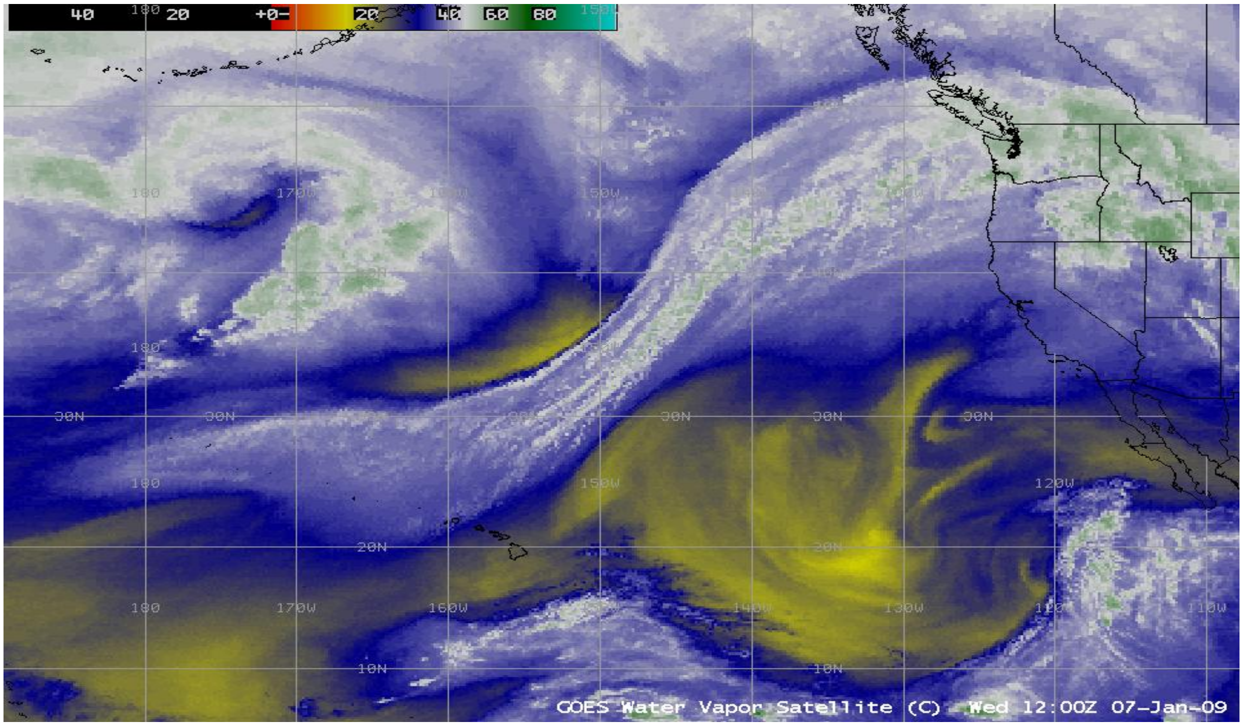
PCIC also reviewed historic weather conditions in the Coquihalla region through weather data retrieved from 17 Environment Canada weather satiations dispersed throughout the region to rationalize results from the RCMs so that there is a meaningful correlation between observed and predicted climatic conditions in the study area.

Based on this analysis, PCIC projected that, over the study timeframe, the Coquihalla Highway will experience:

- Warming with;
    - Increasing hot extremes;
    - Decreasing periods of hard frost;
- Reduction in the range of temperatures;

- Increase in periods of heavy precipitation;
- Decrease in intensity of snow storms and blizzards;
- Moderately decrease in snow frequency; and
- Moderate increase both in magnitude and frequency of Pineapple Express.

Figure 9
Pineapple Express Satellite Image (NOAA GOES-11 2009):



6.2 *Synoptic Analysis*

During the workshop the team struggled with assigning probability scores to Pineapple Express Events.

In order to gain some insight into these events the team invited representatives from Environment Canada to provide professional insight regarding Pineapple Express events. The Environment Canada expert had many years of professional experience in the meteorology of B.C. and was willing to offer synoptic analysis based on this experience. He offered the following observations.

Over the study period:

- Pineapple Express events may increase in intensity by 5 to 10%;
- 70% confident that Pineapple Express events may increase in frequency;
- 90% confident that the frequency of short duration storms will increase; and
- The number of dry days may increase overall.

In general, their assessment was consistent with the results reported by PCIC. There is agreement that Pineapple Express events will likely increase in both frequency and intensity. However, there is still significant uncertainty regarding the magnitude of future storms and the frequency of the events. Nonetheless, the synoptic analysis provided sufficient data to conduct preliminary climate change risk assessment analysis. More work will be required to further characterize these events.

6.3 Sensitivity Analysis

Sensitivity analysis was conducted for a number of climate parameters.

In the absence of synoptic or climate model data, the team arbitrarily assigned a probability score of “3” indicating that it is “moderate or probable” that, over the study period, this parameter will change in a way that adversely affects the infrastructure. Based on these scores, the team completed the risk assessment. Once this work was complete, the team arbitrarily increased the probability score to “4” indicating that the parameter will change such that it “often occurs” over the study period in a way that adversely affects the infrastructure. Based on this change the team reassessed the resulting risk profiles.

7 Risk Assessment Workshop

The Risk Assessment workshop was conducted over a two-day period on March 2 and 3, 2010. The team used this workshop to carry out the analysis defined by Step 3 of the Protocol.

7.1 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 for each relevant infrastructure-climate event 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 8.**

The calculated risk scores arising from this assessment are presented in **Figure 10**.

7.2 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 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.

Figure 10
Summary of Climate Change Risk Assessment Scores

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility
Infrastructure																
Surface - Asphalt	18	9	2	6	2	2	30	30	25							
Pavement Marking											9	18	18	18		
Shoulders (Including Gravel)							36	36	35		3	3	3	18		
Barriers				6								3	3	15		
Curb	6			3									9	9		
Luminaires											12	12	3	12		
Poles											3			9		
Signage - Side Mounted - Over 3.2 m2											3	12	3			
Signage - Overhead Guide Signs					8						3	9	3			
Overhead Changeable Message Signs					8						3	9	3			
Ditches				6			30	36	35	3			3	18		
Embankments/Cuts (Constructed)				18	6	2	36	42	35				3	18		
Hillsides (Natural)				15			30	42	35	9			3	3		
Engineered Stabilization Works				15	2	2	18	30	35							
Avalanche (Inc Protective Works)		3	6	9	2	8	36	36	35	15	18	15	15	18		
Debris Torrents (Inc Protective Works)	14		10	9			42	42	35	15			12	15		
Structures that Cross Streams	6	3		6	8	4	36	42	35		6					
Structures that Cross Roads	6	3		6	8	4	30	36	35		6					
River Training Works (Rip Rap)							36	42	35							
MSE Walls				3				30	30							
Pavement Structure above Sub-Grade		9		12	10											
Catch Basins				3	14		36	36	30	18				12		
Median and Roadway Drainage Appliances				3	14		36	36		18				12		
Sub-Drains		6		3	14	2	18	36								
Third-Party Uutilities							30	30			21					
Culverts < 3m		3		6			42	42	35	15						
Culverts ≥ 3m				3			42	42	35							
Asphalt Spillway and Associated Piping/Culvert		3		6			36	42		15				9		
Environmental Features																
In-Stream Habitat Works	24		4				36	42	35							
Off-Channel Habitat Works	24		4				36	42	35							
Wildlife Fence System										18	18	18	18	18		
Wildlife Crossing Structures																
Vegetation Management	6		4													
Invasive Plants & Pests	12		4			12										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		3	2	15	10	2	24	36	35	15	18	18	9	9		
Ancillary Buildings, Utilities and Yards		3			6	2	6	12	15	15	12	9	9	15		
Communication											18	18	6	12		
Emergency Response		18				2	36	42	35	15	21	18	6	6		
Maintenance (Markings, Crack Sealing)		9	2	12	2	2										

8 Vulnerability Evaluation

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.

Based on calculations of total load and total capacity, the team calculated the vulnerability ratios for the three 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 11**.

Figure 11 Vulnerability

Infrastructure Component	Total Load	Total Capacity	Vulnerability
	L_T	C_T	$V_R = \frac{L_T}{C_T}$
Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	101	88	1.15
Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	153	121	1.26
Catch Basins (Storm Sewers) & Extreme Rainfall	139	117	1.19

8.1 *Discussion*

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 ponding 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.

9 Recommendations

Based on this assessment, BCMoTI identified a number of activities necessary to further resolve the potential climate change risks faced by the Coquihalla Highway. These included:

1. More investigation of the nature and impact of intense rainfall events, including:

    - Investigation of current preliminary design reserve capacity of the Coquihalla Highway to handle changing hydrology from increased local extreme rainfall events.
    - Upgrading affected infrastructure components as a part of regular design and maintenance activities.
    - More detailed studies of the frequency and magnitude of extreme rain events.

2. Requiring contractors to document weather conditions that caused major maintenance issues.

3. Investigate if University of British Columbia (or other) infrastructure failure models contemplate climate as a variable and if this can be adapted to BCMoTI's needs.

4. Develop relevant parameters to measure the interaction between infrastructure design and climate change (as inputs to methodology and modeling). Specifically, use downscale analysis (of Regional Climate Model data) to determine local climate condition changes and match this with design standards of the particular infrastructure under study. This will allow a systematic measurement basis for analysis (may require more complex engineering model use in future, such as, continuous rainfall analysis etc.).

5. Although the team concluded that the results generated by the sensitivity analysis are relatively robust, through more advanced statistical downscaling work, develop better definition of:

    - Frequency of rain on snow events;
    - Frequency of freezing rain events; and
    - Snow accumulation.

6. Further evaluation into high wind / downburst issues. These are potentially very serious on the Coquihalla Highway.

7. More study into visibility issues to define how these issues arise currently on the highway.

    - Based on better definition of current visibility issues, assess the impact of climate change on this matter.

8. Establishing 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.

10 Conclusion

10.1 *Adaptive Management Process*

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

- Assessed the climate change vulnerability of the Coquihalla Highway;
- Developed an understanding of their climate data needs to facilitate future assessments on this, and other, BCMoTI infrastructure;

- Defined an infrastructure component list suitable for application on other BCMoTI highway vulnerability assessments;
- Developed 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.
- Identified a process for reviewing and updating design standards based on climate change predictions.

10.2 Coquihalla Highway Climate Change Vulnerability

Based on this risk assessment, the Coquihalla Highway is generally resilient to climate change with the exception of drainage infrastructure response to Pineapple Express events.

10.3 Areas for Consideration

The BCMoTI study has identified a number of areas for further consideration of climate change implications and impacts. For example, if climate changes in the future, and there are a number of years with wetter than normal weather, how will this affect things like avalanche conditions; and what ramifications will this type weather change have on project construction, operation and maintenance issues. To continue developing an understanding of climate change and adaptation involving transportation infrastructure, BCMoTI is assessing additional study projects in other locations including Northern BC. Results from these studies will further refine transportation infrastructure design standards for the Province of BC.