Introduction to Vulnerability and Adaptation of Infrastructure to Extreme Weather and Climate Changes

Felio, Guy Ph.D. P.Eng. FCSCE
Practice Lead – Special Projects,
Engineers Canada

And

Harshan Radhakrishnan, M.A.Sc., P.Eng.
Practice Advisor, Professional Practice, Standards & Development
Association of Professional Engineers & Geoscientists of BC

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1 CONTEXT

It is fundamentally clear that climate change represents a profound risk to the performance of engineered systems and to public safety in Canada and around the world. As such, engineers, asset managers and decision-makers must address climate change adaptation as part of their primary mandate – the protection of the public interest, which includes life, health, property, economic interest and the environment. Climate change results in significant modifications of statistical weather patterns and consequently can have impacts on design data. Physical infrastructure systems designed using this inadequate data (i.e., data that is less relevant because actual conditions have changed) are vulnerable to failure, compromising public and economic safety.

Engineering vulnerability and risk assessment form the bridge to ensure climate change is considered in engineering design, operations and maintenance of civil infrastructure. Identifying the components of the infrastructure within a system that are highly vulnerable to climate change impacts enables cost-effective engineering, operations and policy solutions to be developed.

1.1 Objectives and Limitations

This article intends to inform decision-makers and infrastructure practitioners about some of the tools that consider climate change impacts to infrastructure, from planning to operations and maintenance. It offers a brief review of selected methodologies that have been used in Canada to develop integrated community adaptation plans, to assess the climate components in policy, and to evaluate the engineering vulnerability of infrastructure assets and systems. It focuses on processes and methods that have been used by public agencies and municipalities to identify and quantify risks, as well as to develop climate change adaptation solutions. It is not intended to provide an exhaustive list of all the methodologies that have been used or have been published on the subject.

The fact that a particular tool is presented in this article does not constitute an endorsement. If a tool has been omitted, it is because of space or scope limitations, and should not be construed as a rejection of the tool as beneficial.

The information and statements expressed in this article are those of the author and do not reflect the views, opinions or any official position of Engineers Canada.

1.2 Current and Future Climate

The changes in global climate have been, and continue to be well documented by a number of Canadian and international organizations such as the Intergovernmental Panel on Climate Change (IPCC) which produced its Fifth Assessment Report (AR5) in November 2014. In brief, the report tells policymakers what the scientific community knows about the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

From an infrastructure's perspective, the story of climate change can be seen in the increasing number of occurrences of extreme weather events and their impacts. Table 1 presents the "billion dollar years" of payouts by Canadian insurers. Of note is the increased frequency of those devastating years, and the fact that 2013 was the first time ever insurance companies paid in excess of two billion dollars for losses.

Table 1. Billion-dollar payment years from Canadian insurance companies

Year	Main event(s) causing losses
1998	Due solely to the Eastern Canada ice storm
2005	Greatly due to the August 19 Greater Toronto Area (GTA) rainstorm
2009	Mainly due to back-to-back windstorms in Alberta
2010	Due greatly to large hailstorm in Alberta
2011	Mainly because of the Slave Lake wildfire
2012	Caused mainly by one large and two smaller hailstorms in Alberta
2013	Due to the Southern Alberta flood and GTA flood. First time ever for two billion-dollar events

It is therefore no coincidence that the Institute for Catastrophic Loss Reduction (ICLR) reported that:

> "Large insured losses from extreme weather appear to be 'the new normal' for the Canadian insurance industry, expecting that large-loss years will no longer be rarities." (Canadian Underwriter, November 2012).

1.3 Canada's Infrastructure Context

Public infrastructure systems are complex, often underground and therefore difficult to access and inspect. It is standard practice to differentiate between linear assets (pipes, roads, cables, etc.) and non-linear or discrete assets (pumps, plants, bridges, culverts, etc.) since each category presents different management challenges. However, providing services to the public requires all the components within a system to perform adequately since the robustness – and therefore the safety and quality of the service is dependent on its weakest link.

Infrastructure assets also have very long service lives – water or sewer pipes for example are commonly in use for 80 years, 100 years or longer – four generations or more. It is therefore critical that these assets be properly planned and managed.

Figures 1 and 2 show the condition distribution of core public infrastructure systems reported by the 2012 Canadian Infrastructure Report Card (CIRC). In general, with the exception of municipal roads, the 2012 CIRC shows that underground systems (water, wastewater and storm water) are in good condition.

It is important to note that the data reported is about the physical condition of the infrastructure. Although the 2012 CIRC attempted to collect information on other performance indicators, particularly capacity, the data received was not sufficient to provide statistically relevant results.

In regards to the physical condition of stormwater systems, it should be noted that these are "young" relative to other core infrastructure such as roads or wastewater systems. Regulations regarding managing stormwater, particularly in new residential developments, are recent and therefore it is expected these infrastructures are in a better condition as shown by the data.

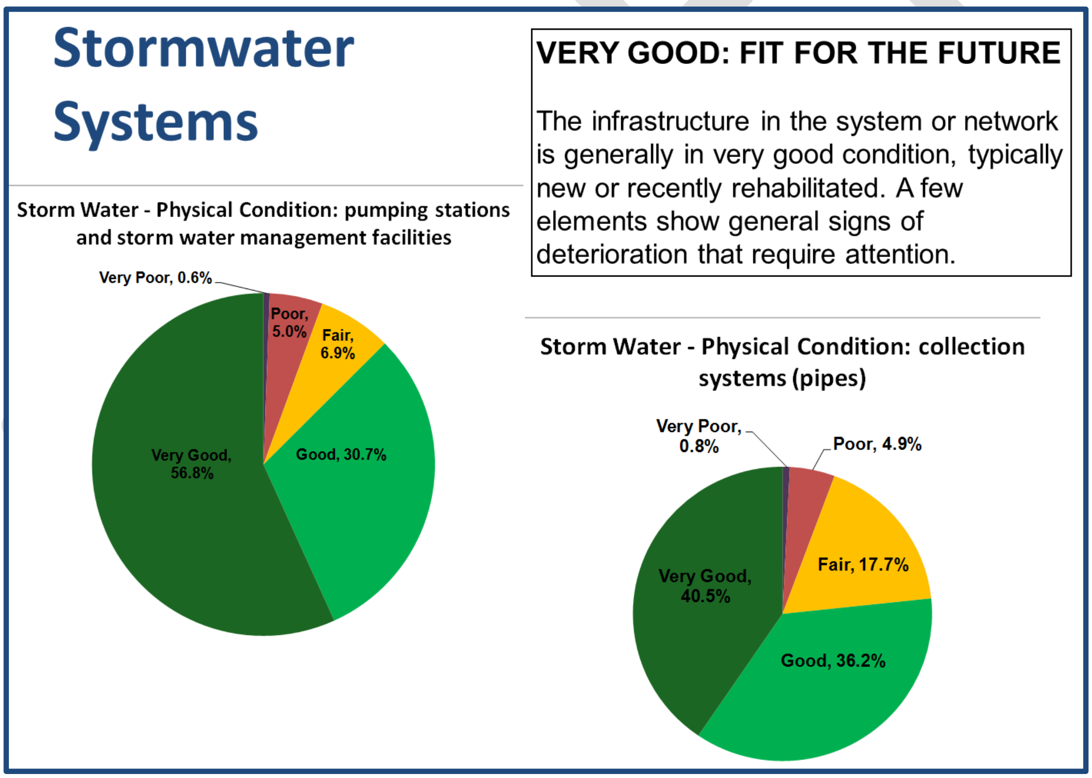


Figure 1: Canadian Infrastructure Report Card (2012) Results for Stormwater systems

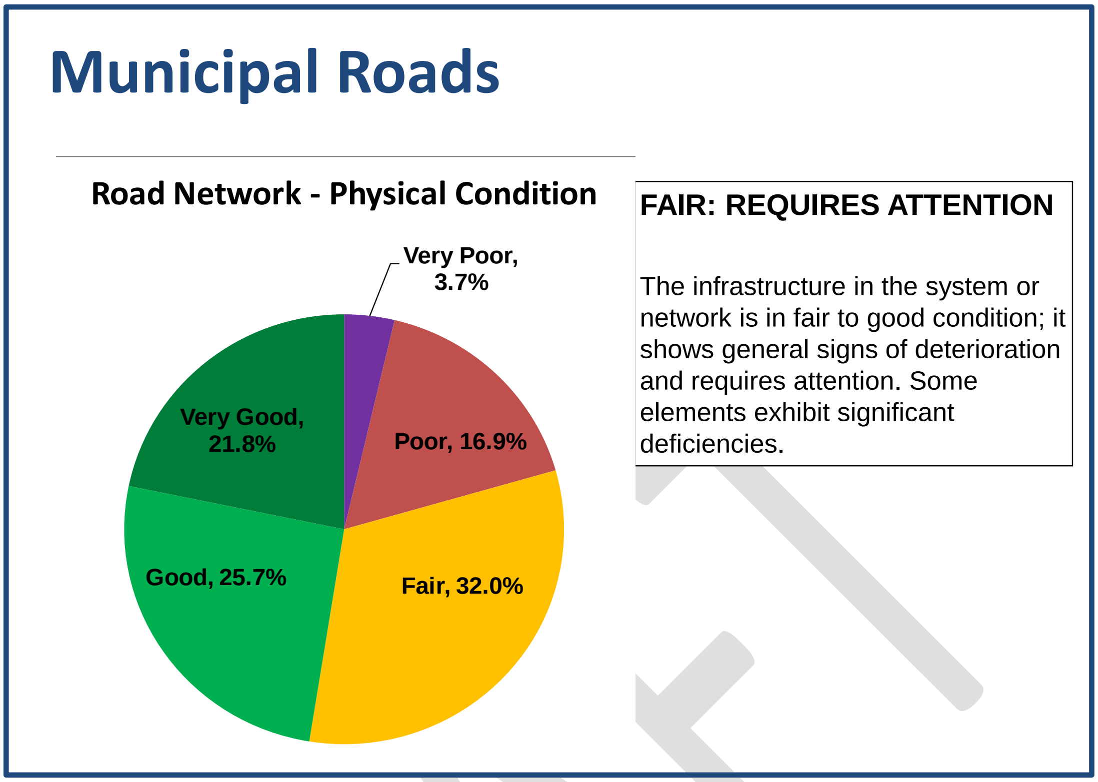


Figure 2: Canadian Infrastructure Report Card (2012) Results for Municipal Roads

These data are but snapshots of the condition of various infrastructure systems. The 2012 CIRC also found that asset management is, and will continue to be a critical activity to maintain and improve levels of service under the financial constraints municipal governments experience. As a result, the report card partners issued an Asset Management Primer in September 2014. In the context of risk management, the Primer indicates:

> "Understanding and managing the risks associated with the failure of an asset is a key element in many AMPs (Asset Management Plans). The risks in municipal infrastructure are impacted by the physical condition of the asset and the social, economic and environmental consequences that would occur if the asset fails to provide the service for which it was designed."

1.4 Managing Infrastructure and Risks

Establishing the exposure and sensitivity of infrastructure to threats, whether from natural causes such as extreme climate events or earthquakes, or from man-made sources is an integral part of sound asset management. Figure 3 illustrates an asset management framework developed by the author and inspired by the InfraGuide best practice DMIP 7 – Managing Infrastructure Assets (2007) and that is compatible with the intent of ISO 55000 – Asset Management. Providing the details of this framework is beyond the scope of this paper. There are however a number of steps in this framework that relate to and are influenced by current and future climatic conditions. For example, future loads on the infrastructure, whether from increased utilisation or changes in climate, may affect the physical condition, functionality or capacity of the infrastructure. This, combined with the infrastructure's current condition, can produce vulnerabilities and risks that require short term attention or that will need to be addressed in future capital or maintenance plans.

2 INFRASTRUCTURE SUSTAINABILITY, VULNERABILITY AND RESILIENCE: TOOLS AND PROCESSES

2.1 Definitions

In 1987, the Bruntland report from the World Commission on Environment and Development defined sustainability as "meeting the needs of the present generation without compromising the ability of future generations to meet their needs."

<u>Sustainable Infrastructure</u>

The US-EPA interprets this definition in the context of infrastructure as:

> "Sustainable (infrastructure) means having an active and effective program for renewal and replacement of components at a rate that allows for that infrastructure to continually serve our communities into the future. Achieving sustainability requires the establishment of a long-term plan to gradually and continually replace all infrastructure assets—a plan that ensures wise spending practices and a stable revenue stream for continuous support of needed future investments."

<u>Infrastructure Vulnerability</u>

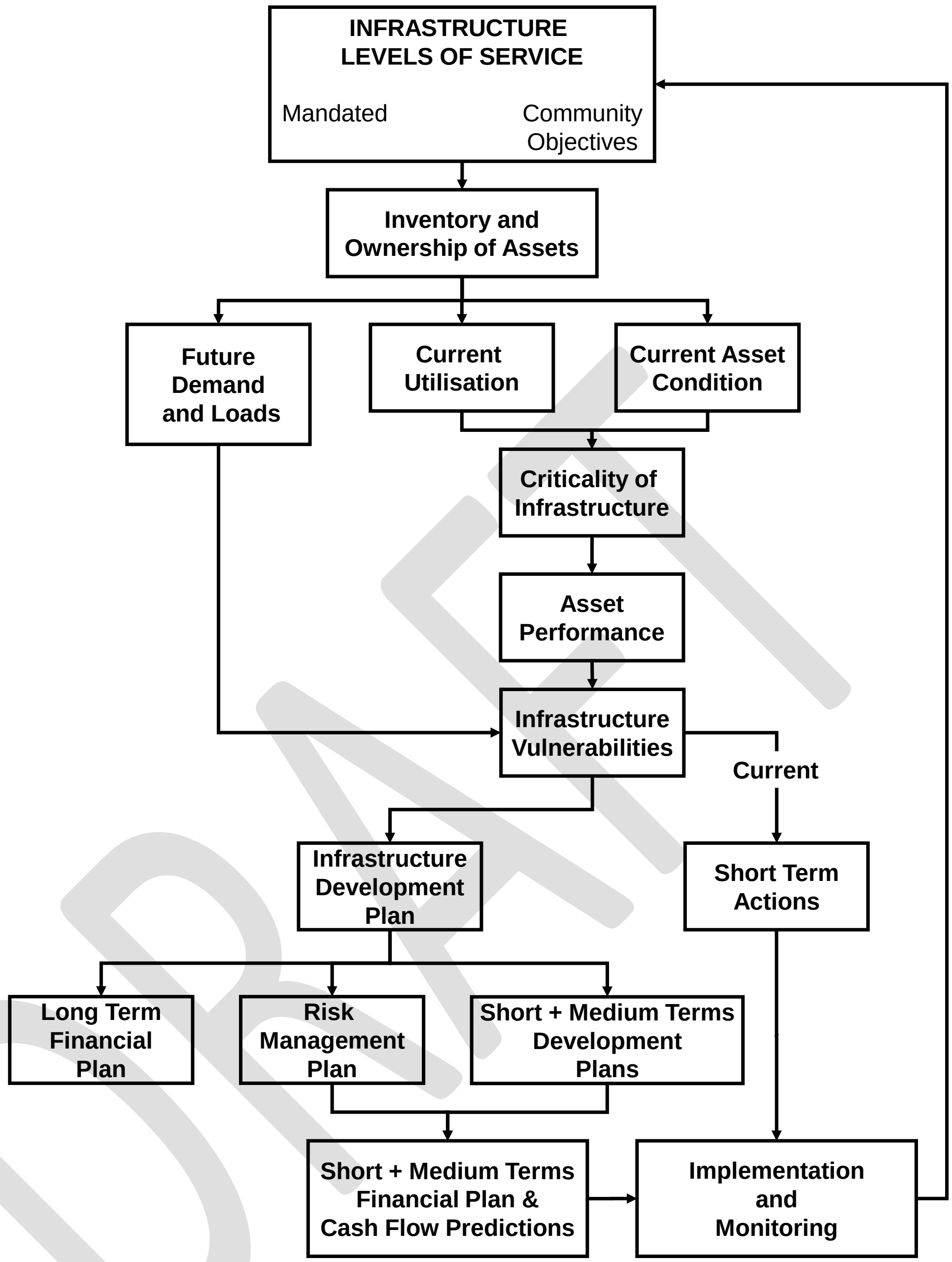
Engineers Canada's PIEVC Protocol defines the engineering vulnerability of infrastructure as:

> "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity."

Engineering 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.

An engineering vulnerability assessment will therefore require assessing all three elements above. Although this definition is given in the context of climate change, it is applicable to any hazard or threat the infrastructure may be exposed to.



Notes:
- Future Demand is based on community growth and vision.
- Asset performance measures structural performance, capacity and functionality, and relates to the mandated levels of service, community objectives and regulatory requirements including codes/standards.
- Risk is assessed with respect to health, safety, economic and environmental (e.g. climate change) impacts.
- Short term actions are to remedy any deficiencies for which short term risk is not acceptable.
- Long-term plans include: demand management, alternative service delivery, partnerships, etc.

Figure 3: Example of asset management framework incorporating risk management planning (Source: author)

Infrastructure Resilience

Resilience, on the other hand, is the capacity of the infrastructure to withstand and operate under hazards or threats. The UN International Strategy for Disaster Reduction defines resilience as:

> "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions."

2.2 Community Assessment/Climate Change Adaptation Planning

In Canada, municipalities in some provinces have been required to produce Integrated Community Sustainability Plans (ICSPs) or variations thereof to receive Federal Gas Tax funds. The level of details about infrastructure condition, rehabilitation and replacement needs and long-term plans varies across the country since the requirements were defined under each Federal – Province/Territory agreement. In Nova Scotia, for example, municipalities were required to incorporate climate change into their ICSP beginning in 2013. A Municipal Climate Change Action Plan (MCCAP) Guidebook was developed to provide municipalities with a step-by-step process to follow. It is not known how climate change impacts to infrastructure have been considered in these plans or in other jurisdictions, but should be assessed.

A number of sustainability planning and enterprise risk management tools that address extreme weather and climate change exist and are currently used, including:

- ICLEI's Changing Climate, Changing Communities Framework: a milestone framework that guides local government practitioners through a process of initiation, research, planning, implementation and monitoring for climate adaptation planning. It is available through a subscription with ICLEI (www.icleicanada.org/programs/adaptation/barc).
- City of Toronto Climate Change Risk Assessment: The City of Toronto has a comprehensive assessment process that is based on ISO 31000 and aligns with ISO 14000.
- Atlantic Canada Climate Adaptation Solutions Association: *7 Steps to Assess Climate Change Vulnerability in Your Community* (see http://atlanticadaptation.ca/)

2.3 Engineers Canada – PIEVC Infrastructure Engineering Vulnerability Assessment

Engineers Canada, with support from Natural Resources Canada (NRCan) created the Public Infrastructure Engineering Vulnerability Committee (PIEVC) in 2005 to address engineering concerns with infrastructure risks to climate change impacts. By 2008, the PIEVC had created a tool, the PIEVC Engineering Protocol ("the Protocol"), to guide engineers working with other professionals in assessing the engineering vulnerability of infrastructure and develop adaptation solutions. An engineering tool, the Protocol helps assess vulnerabilities in several related areas such as planning, operations and maintenance of the infrastructure.

Initially targeted to water resources infrastructure (potable water, wastewater and storm water), roads, bridges, and buildings, the PIEVC Protocol has since been applied to a wider spectrum of infrastructure, including dams, coastal structures, airports and electrical transmission grids and distribution networks. As of April 2015, the Protocol has been or is being used for more than 40 risk evaluations in Canada as shown in Figure 4, and two have been completed outside Canada: Honduras and Costa Rica. There are no known limitations to the type of infrastructure the Protocol can be applied to. It has been used in small (e.g., District of Shelburne, NS – population about 3,000) and large (Toronto, ON) municipalities across Canada. The complete list of applications can be found at www.PIEVC.ca

Figure 4: Locations and Type of Protocol Vulnerability Assessments Completed or in Progress as of February 2013

The Protocol is based on the same principles of risk assessment that are used in assessing other types of risk e.g. business, health, etc., and aligns with ISO 31000 Risk management. The five-step risk screening process systematically reviews historical climate information and projects the nature, severity and likelihood of future climate changes and events. It also establishes the adaptive capacity of an individual infrastructure as determined by its design, operation and maintenance. It includes an estimate of the severity of climate impacts on the components of the infrastructure (i.e. deterioration, damage or destruction) to enable the identification of higher risk components and the nature of the threat from the climate change impact. This information can be used to make informed engineering judgments on what components require adaptation as well as how to adapt them e.g. design adjustments or changes to operational or maintenance procedures.

The Protocol provides a profile of high, medium and low risks to infrastructure from climate impacts at a screening level. It does not require comprehensive and complete data to complete an assessment. Gaps are addressed by professional judgment and experience of the inter-disciplinary team of professionals needed to define the nature and consequence of climate impacts that damage or destroy infrastructure or impede its service to the community it serves.

Experience has shown that screening level risk assessment of infrastructure climate risks produces cost-effective and timely evidence at an affordable cost to large and small communities. Recommendations to address the highest risks to improve climate resilience range from collecting more data or more targeted and quantitative engineering analysis to adjustments in operations and maintenance policies and procedures to design improvements that require additional cost information.

Engineers Canada has also completed the initial development and testing of a Triple Bottom Line Decision Support Module. This tool evaluates adaptation recommendations from the Protocol using a multi-factor analysis that includes social, environment and economic factors. Engineers Canada offers this additional tool as a complement to the Protocol.

Following is an illustration of the vulnerability assessment of transportation infrastructure using the PIEVC Protocol. The full report for this and other case studies can be downloaded from www.PIEVC.ca

<u>BC Ministry of Transportation and Infrastructure (MoTI) Yellowhead Highway 16 between Vanderhoof and Priestly Hill (March 2011)</u>

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 principal objective of this case study was to identify those components of the Yellowhead Highway 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.

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 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.

Table 2 below provides a list of the climate parameters and infrastructure indicators selected for the risk assessment; Table 3. Presents the infrastructure components considered in the study.

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.

The Pacific Climate Impacts Consortium (PCIC) provided climate modeling for the study. PCIC used five Global Climate Models (GCMs) to project future global climatic conditions, and five Regional Climate Models (RCMs) to obtain regional estimates for the area of the Yellowhead Highway.

Table 2. Climate Parameters and Infrastructure Indicators used for the Yellowhead Hwy. 16 Risk Assessment (Source: BC-MoTI report accessed at www.PIEVC.ca)

Climate Parameter	**Infrastructure Indicator**
High Temperature	Day(s) with maximum temperature exceeding 35^{o}C
Low Temperature	Day(s) with minimum temperature below -35^{o} C
Average Temperature	Average maximum temperature over 7 days
Temperature Variability	Daily temperature variation of more than 25 ^{o} C
Freeze / Thaw	85 or more days where maximum temperature > 0^{o} C and minimum temperature < 0^{o} C
Frost / Frost Penetration	47 or more consecutive days where minimum temperature < 0^{o} C
Total Annual Rainfall	406.7 mm
Extreme High Rainfall	> 35 mm rain
Sustained Rainfall	≥ 5 consecutive days with > 25 mm rain
Longer Sustained Rainfall	≥ 23 consecutive days with > 10 mm rain
Low Rainfall	≥ 10 consecutive days with precipitation < 0.2 mm
Prolonged Dry Periods (Drought)	≥ 112 consecutive days with precipitation < 0.2 mm
Snow (Frequency)	Days with snow fall > 10 cm
Snow Accumulation	5 or more consecutive days with a snow depth > 60 cm
Snow Storm / Blizzard	8 or more days with blowing snow
Rain / Snow / Wind	Rain on snow including temperature and wind speed
Rain on Snow	10 or more consecutive days with rain on snow
Hail / Sleet	Days with precipitation falling as ice particles
Rain on Frozen Ground	Precipitation > 6 mm/3h
Freezing Rain	9 or more days with rain that falls as liquid and freezes on contact
Visibility	≥ 15 hours per year with visibility < 1,000 m
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 ^{o} C

The results from the PCIC work are summarized below.

- 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.

Table 3. Infrastructure Components Listing for the Yellowhead Hwy. 16 Risk Assessment (Source: BC-MoTI report accessed at www.PIEVC.ca)

Above Ground		**Below Ground**	
1	Asphalt - Hot in Place	25	Pavement Structure
2	Asphalt - Seal Coat	26	Catch Basins
3	Pavement Marking	27	Roadway Drainage Appliances
4	Shoulders (Including Gravel)	28	Sub-Drains
5	Barriers	29	Below Ground Third Party Utilities
6	Curb - Concrete	30	Above Ground Third Party Utilities
7	Curb - Asphalt	31	Culverts < 3m
8	Luminaires	32	Culverts ≥ 3m
9	Poles	33	Piping/Culvert - Below Ground Elements.
10	Signs - Sheeting	**Miscellaneous**	
11	Signs - Wood or metal bases	35	Winter Maintenance
12	Signage - Side Mounted - Over 3.2 m^2	36	Habitat Features
13	Signage - Overhead Guide Signs	37	Routine Maintenance
14	Overhead Changeable Message Signs – Weigh Scale	38	Pavement Marking Repair
15	Ditches	39	Pavement / Curb/ Barrier / Sign Repair
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		

The PIEVC 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. Table 4 outlines the risk thresholds used for this risk assessment.

Table 4. Risk Tolerance Thresholds and Colour Codes for the Yellowhead Hwy. 16 Risk Assessment (Source: BC-MoTI report accessed at www.PIEVC.ca)

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 risk for each interaction climate event – infrastructure component is calculated in two steps. First, PCIC and representatives from the team with climate expertise consulted and assigned probabilities for the climate parameters. Second, at a team workshop, the subject matter experts 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. Figure 5 illustrates the results from this step.

Some of the recommendations from the study follow.

- Investigate current design reserve capacity of the Yellowhead Highway to handle changing hydrology from increased local extreme rainfall events.
- 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).
- 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.
- 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.
- Further analysis on the vulnerability of culverts < 3m is recommended due to the uncertainties in the climate models and lack of survey information.

- Further assessment is recommended for the Ross Creek culvert to determine if upgrade or retrofit will be required even to handle the existing load.
- Monitor the impact of extreme high temperature on concrete bridge structures.
- 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.
- 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
- Conduct more study into visibility issues to define how these issues arise currently on the highway. Once BC MoTI has developed a better definition of current visibility issues, they should assess the impact of climate change on this matter.

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		

Figure 5: Partial List of Climate Change Risk Assessment Scores. Yellowhead Hwy. 16 Risk Assessment (Source: BC-MoTI report accessed at www.PIEVC.ca)

3 APEGBC Guidelines on Incorporating Climate Resilience in the Design of Public Infrastructure in BC

The Association of Professional Engineers and Geoscientists of BC (APEGBC) regulates and governs the engineering and geoscience professions in British Columbia. The Association has over 30,000 practicing members and registrants and constitutes one of the larger associations regulating the practice of professional engineering and geoscience in Canada. Individuals licensed by APEGBC are the only persons permitted by law to undertake and assume responsibility for engineering and geoscience projects in B.C. Engineers and/or Geoscientists are actively involved in almost every community or infrastructure project undertaken in Canada, making their impact unparalleled in effecting climate change adaptation measures.

APEGBC is charged with protecting the public interest by setting and maintaining high academic, experiential and professional practice standards for its members. In accordance with the Engineers and Geoscientists Act [RSBC 1996] c. 116, APEGBC has the expressed legal authority to establish, maintain and enforce standards of practice. The Association does this through the development of professional practice guidelines which establish the standard of care APEGBC professionals must follow when carrying out a range of professional activities.

APEGBC has produced over 30 professional practice guidelines relating to the establishment of the standard of care to be applied when members carry out a particular professional activity relating to their field of practice. From seismic retrofits, to dam safety, these guidelines cover a range of professional activities dealing with a variety of fields of practice. As a result, they are of tremendous benefit to APEGBC members and registrants who ultimately impact the design and construction of the built infrastructure in which we live. To date, such guidelines have been produced in collaboration and with funding support from over 10 different provincial government ministries/agencies. Importantly, they provide guidance on how APEGBC professionals can carry out professional activities in response to the requirements in a variety of provincial legislation. A list of these guidelines can be found by visiting this site:
www.apeg.bc.ca/guidelines

APEGBC, through its Climate Change Advisory Group, has published a position paper on climate change (available at: www.apeg.bc.ca/climatechange) as it relates to the practice of professional engineering and geoscience. APEGBC recognizes that the climate is changing and commits to raising awareness about the potential impacts as they relate to the practice of engineering and geoscience, and to providing information and assistance to members in managing implications for their own professional practice.
A changing climate in BC means evolving responsibilities for APEGBC members. Professional engineers, professional geoscientists, provisional members, limited licensees, engineers-in-training and geoscientists-in-training are expected to keep themselves informed about the changing climate, and consider potential impacts on their professional activities.

In addition to existing professional practice guidelines and professional development courses, APEGBC will be developing further tools and resources to assist members in understanding and addressing the potential impacts of a changing climate on their professional practice. The APEGBC Professional Practice Guidelines - Legislated Flood Assessment Guidelines for a Changing Climate in BC (available at: https://www.apeg.bc.ca/getmedia/18e44281-fb4b-410a-96e9-cb3ea74683c3/APEGBC-Legislated-Flood-Assessments.pdf.aspx), are one example of existing guidelines that inform the APEGBC professionals the standard of care to be applied while conducting flood assessment mandated by Provincial legislation.

Recently, APEGBC has partnered with the BC Ministry of Transportation and Infrastructure (MoTI) on the creation of Professional Practice guidelines relating to climate change adaptation to provide engineers and geoscientists working on MoTI projects information on how to conduct risk assessments so their designs address a changing climate. The risk assessment component of this guideline will be based on the PIEVC protocol (but engineers will be free to use other models if they choose). Because this field of practice is evolving, in addition to establishing the standard of care that will be applied by APEGBC members, these guidelines seek to address:

- climate science, as it applies to practice of professional engineering and professional geoscience,
- the tools available to assess risk to Ministry infrastructure's due to climate change
- resources available for professionals to help with incorporating climate change adaptation in designs,
- quality management in professional practice,
- adaptation design examples from practicing professionals and,
- education and training requirements.

The completed draft guideline document is expected to be completed by March 31st 2016. These guidelines will help develop a common level of expectation amongst a variety of stakeholders while establishing minimum acceptable standards of practice for APEGBC members and licensees. More importantly, the report and the assurance statement prepared based on these guidelines will allow professionals to convey to the decision makers:

- the risks associated with the infrastructure,
- the possible future climate scenarios that the infrastructure may be subjected to;
- the uncertainties associated with the assessment,
- the assumptions made by professionals in arriving at the recommendations, and,
- the tools and resources that were used in the assessment.

It is hoped that by conveying the information in a simple and consistent manner, the decision maker is provided with the information from which the design decisions have been made. As the tools and models used in design adaptation work are evolving, these guidelines will instruct the professional to inform the decision maker the versions of the tools and the climate models have been utilized in design adaptation.

4 CONCLUSION

While the tools reviewed here provide valuable information for engineers, asset managers, planners and decision-makers, the PIEVC Protocol has the engineering depth and breadth of application to help communities large and small adapt their particular infrastructures to a changing climate. The PIEVC Protocol is a very useful tool and process in engaging engineers to work closely with other professionals to support the planning, operation, maintenance, management and use of the infrastructure to the benefit of society. The results inform decision-makers to a level that is adequate and timely enough to develop cost-effective recommendations that adapt the highest risk components to improve their resilience to climate impacts in ways other assessment tools may not.

There are other tools and methodologies that have been developed in other countries. For example, several US Federal agencies including the Federal Highway Administration, have created methodologies for detailed quantitative risk assessments and comprehensive climate change adaptation planning for very large capital-intensive projects. There also exist similar tools developed in Europe and Australia that require quantitative data.

It is also important to note that most, if not all methodologies, including those presented here, fit the general ISO 31000 Risk Management principles and framework. In the medium to long-term, compliance of all these methodologies with ISO 31000 would be a desirable outcome.

5 ACKNOWLEDGEMENTS

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