TOOLS TO EVALUATE THE VULNERABILITY AND ADAPTATION OF INFRASTRUCTURE TO CLIMATE CHANGE

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Abstract:

It is clear that climate change represents a significant risk to the performance of engineered systems and to public safety in Canada. 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 interests and the environment. 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 that are highly vulnerable to climate change impacts enables cost-effective engineering, operations and policy solutions to be developed. This paper puts future climate risks in the context of the current condition of Canada's infrastructure and the impacts of climate change. It presents a high level overview of some of the tools available to decision-makers and infrastructure practitioners to consider climate change impacts, from planning to operations and maintenance. The article focuses on processes and methodologies that have been used by public agencies and municipalities in Canada to identify and quantify risks, as well as develop climate change adaptation solutions. Engineers Canada's PIEVC Protocol, a methodology used in more than 40 projects across Canada to evaluate the vulnerability of infrastructure is described in more details. The Protocol has been applied to a wide spectrum of infrastructure: roads, highways, bridges and associated structures; potable water, wastewater and storm water systems; electrical transmission infrastructure and dams; buildings; airports; and coastal infrastructure. The applications cover all regions of Canada.

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 paper 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 to develop 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 methods that have been used by public agencies and municipalities to identify and quantify risks, as well as 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 compelling story about climate change impacts can be seen in the increase number of occurrences of extreme 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.

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

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

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

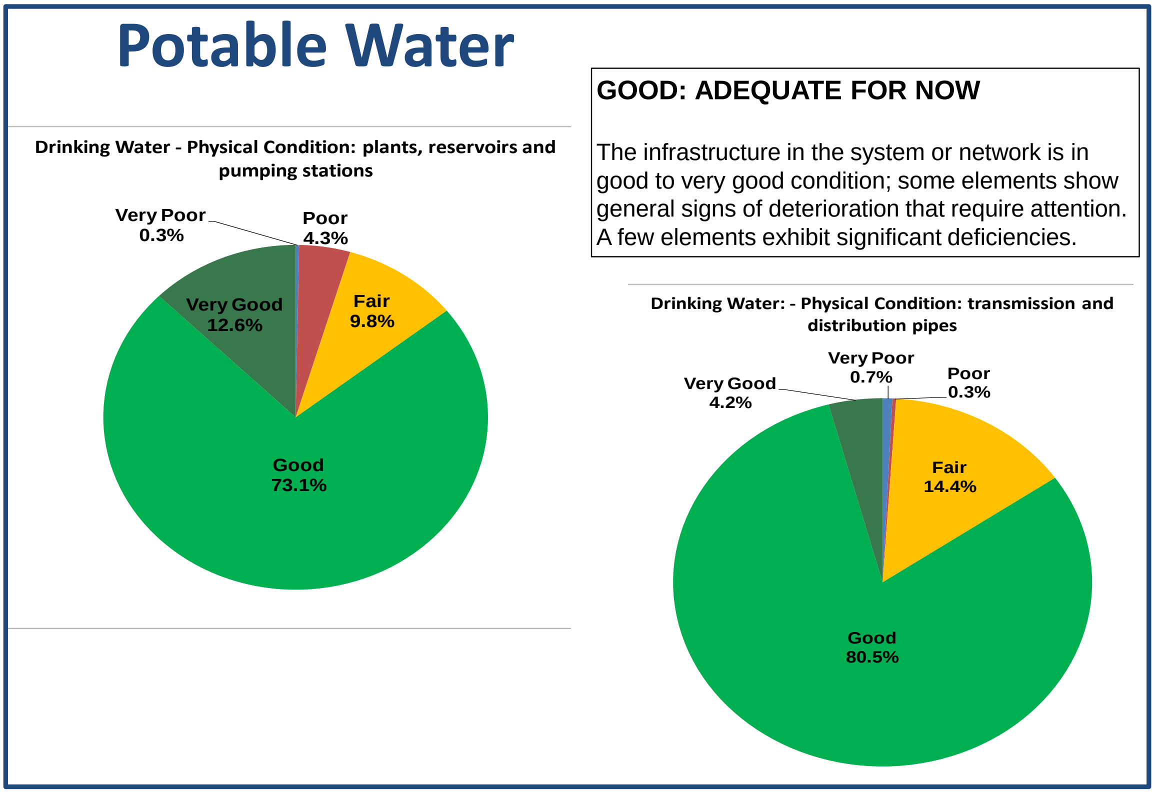
Public infrastructure systems are complex, most of them underground and therefore difficult to access and inspect. It is standard practice to differentiate between linear assets (pipes, roads, cables, etc.) and non-linear or discrete assets (pumps, plants, bridges, culverts, etc.) since each category presents different type of 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.



Potable Water

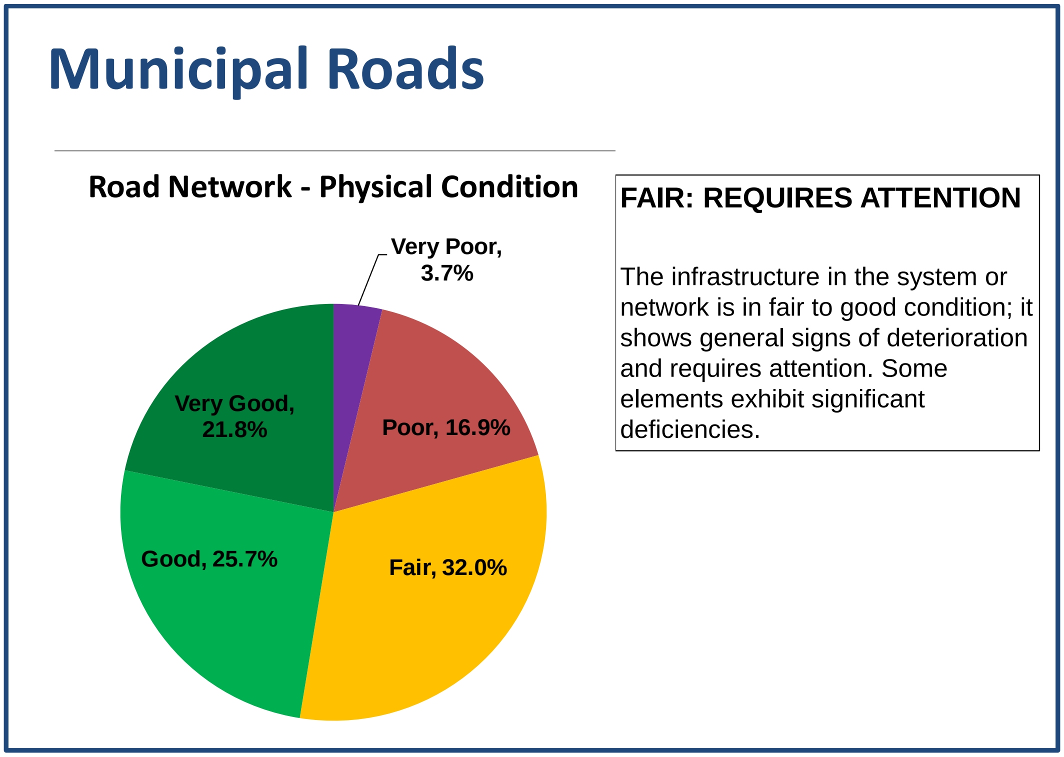
GOOD: ADEQUATE FOR NOW

The infrastructure in the system or network is in good to very good condition; some elements show general signs of deterioration that require attention. A few elements exhibit significant deficiencies.

Figure 1: Canadian Infrastructure Report Card (2012) Results for Potable Water Systems

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.”



Municipal Roads

FAIR: REQUIRES ATTENTION

The infrastructure in the system or network is in fair to good condition; it shows general signs of deterioration and requires attention. Some elements exhibit significant deficiencies.

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

1.4 Managing Infrastructure and Risks

Establishing the exposure and sensitivity of infrastructure to threats, whether from natural sources such as extreme climate events or earthquakes, or from man-made sources is an integral part of sound asset management. Figure 4 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 (2014). 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 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-Environmental Protection Agency 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."

Infrastructure Vulnerability

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.
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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.

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:

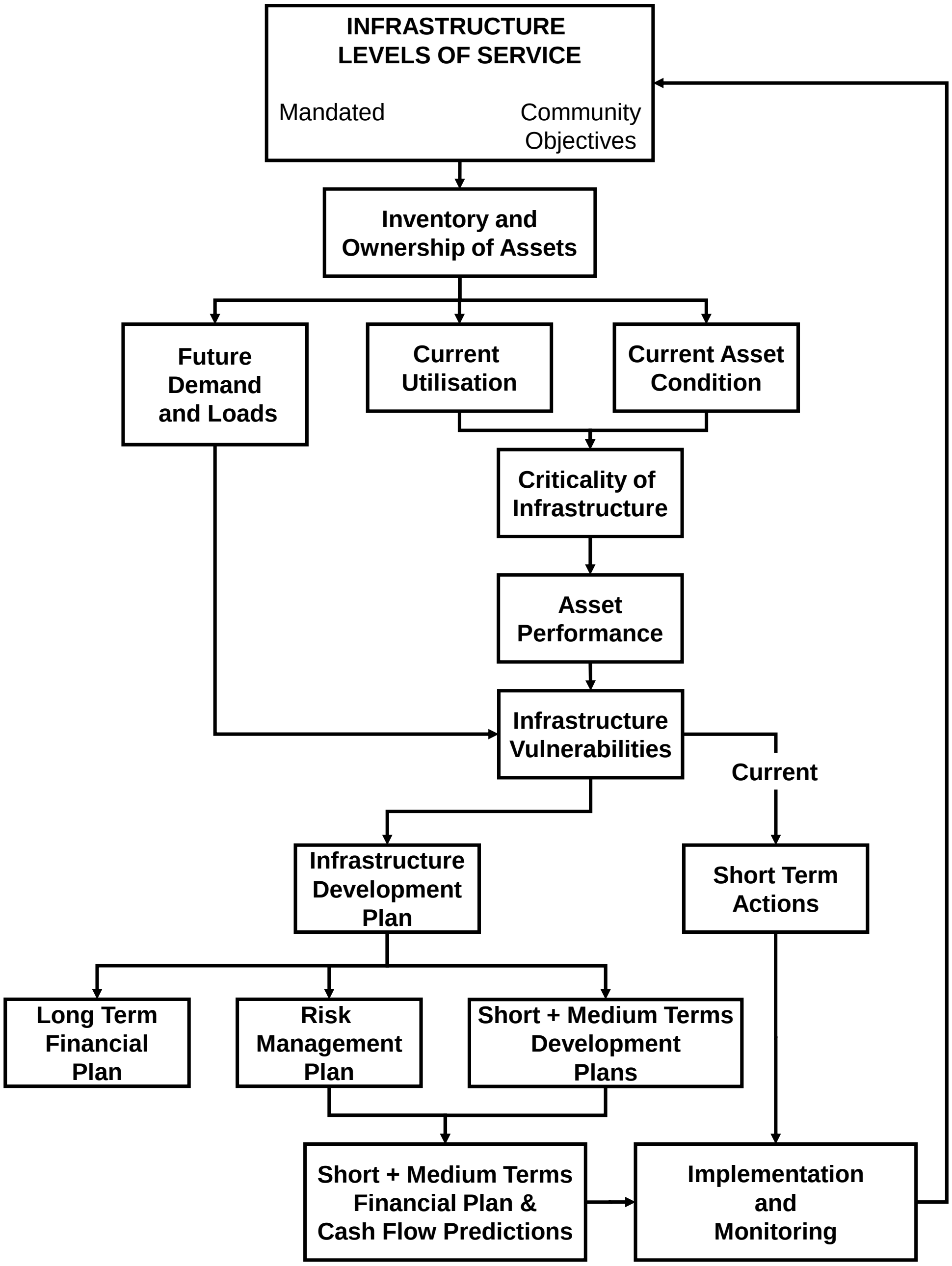
> "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions."

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. It is not known how climate change impacts to infrastructure have been considered in these plans or in other jurisdictions, but should be assessed.

2.2.1 ICLEI: Changing Climate, Changing Communities Framework

The International Council for Local Environmental Initiatives (ICLEI) has developed a milestone framework, Changing Climate – Changing Communities, to guide local government practitioners through a process of initiation, research, planning, implementation and monitoring for climate adaptation planning. This five step process (Figure 5) is supported by an online interactive tool, the Building Adaptive and Resilient Communities (BARC) designed to assist communities in adapting to the impacts of climate change through the development of a Municipal Climate Change Adaptation Plan and is available through a subscription with ICLEI.



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

The process can be applied at various levels within a community or municipality:

- At the single sector or department level
- For a municipal operations plan covering all departments
- For a community wide plan with multi-stakeholder, community involvement
- Community driven for a vulnerable sector within a municipality (e.g., residents from a flooded area)

2.2.2 7 Steps to Assess Climate Change Vulnerability in Your Community Guide and Worksheets

The Atlantic Climate Adaptation Solutions Association has produced a guidance document and workbook called *7 Steps to Assess Climate Change Vulnerability in Your Community.*

1. Identify the types of climate and weather-related issues that have affected your community;
2. Locate where these issues have occurred or could occur in your community;
3. Assess what infrastructure has been or will be impacted;
4. Identify the residents who have been or will be most affected as well as those who can provide assistance in the community;
5. Assess which economic sectors have been or will be most impacted by the issues;
6. Identify how the natural environment has been or will be affected; and
7. Determine the best ways to address the issues identified.

The workbook produced for Newfoundland for example, includes climate (current, future predictions) information as well as expected trends and impacts from, for example, precipitation (intensity, frequency), temperature (average, extremes) and sea-level rise.

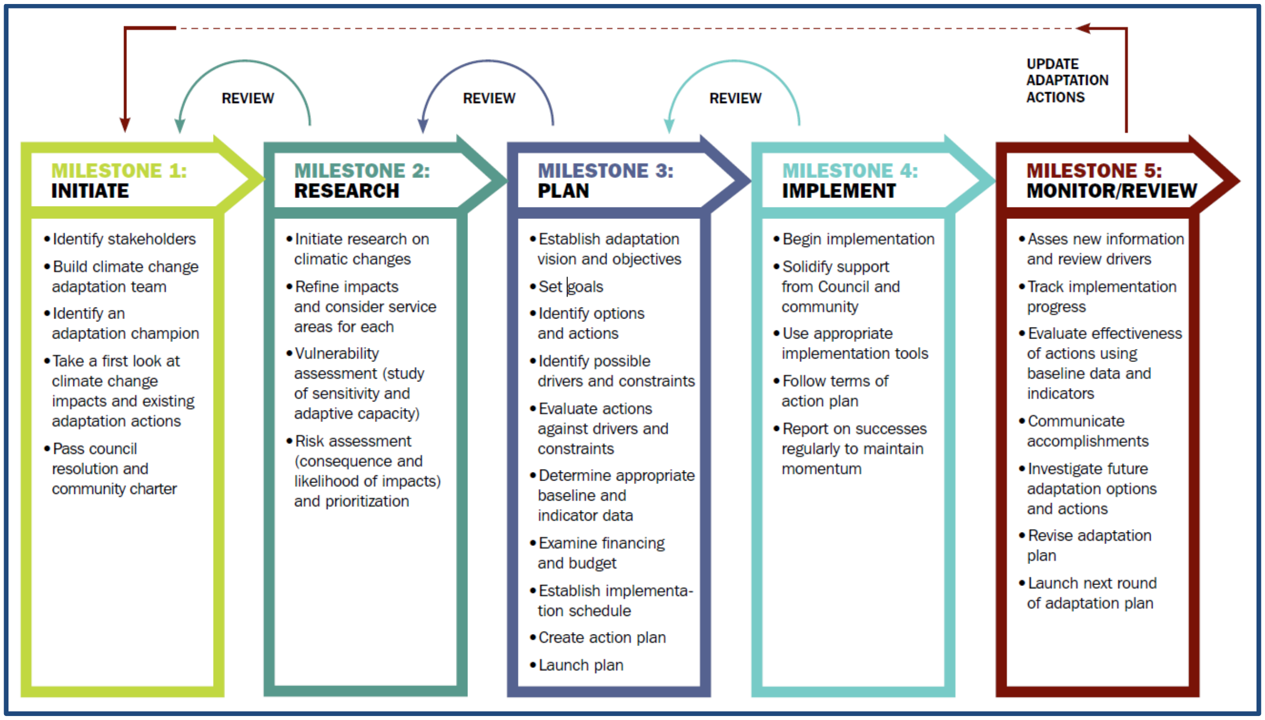


Figure 5: ICLEI's five-step milestone framework (Source: ICLEI).

2.3 Residential Basement Flood Vulnerability Assessment Tool - MRAT

In 2013, the Insurance Bureau of Canada (IBC) launched its Municipal Risk Assessment Tool (MRAT) through pilot applications in three cities: Fredericton (NB), Hamilton (ON) and Coquitlam (BC).

MRAT focuses on basement flooding risks, and more particularly on mapping vulnerable areas to flooding within a city. The tool uses data from municipal infrastructure (inventory and condition), land use, current and predicted future climate, and insurance claims through a risk formula that uses the traditional definition that considers the probability of climate events occurring (in this case precipitation and resulting floods), the exposure (infrastructure interacting with the particular climate event) and the vulnerability which establishes the susceptibility of the infrastructure to the climate event Figure 6 illustrates the results expected from the application of MRAT to a municipality.

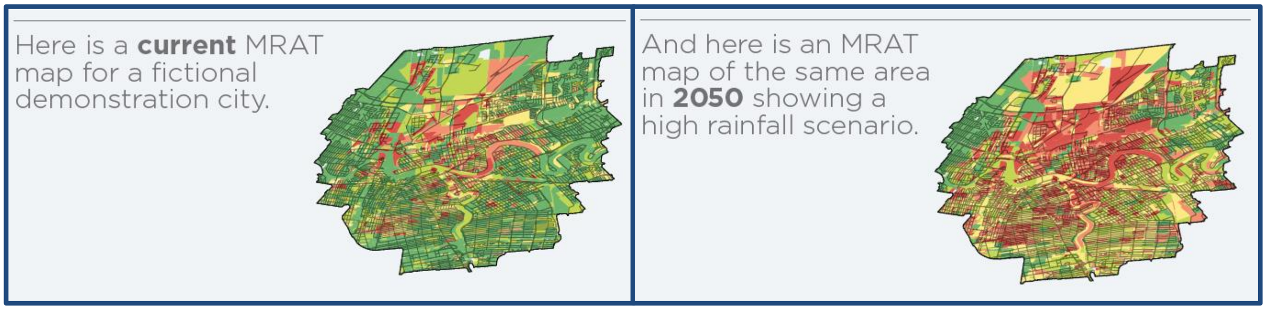


Figure 6: Illustration of MRAT basement flooding risk maps (Source: IBC)

2.4 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 Protocol, to guide engineers working with other professionals in assessing the vulnerability of infrastructure and develop adaptation solutions. Although 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 its inception been used for a wider spectrum of infrastructure, including dams, coastal structures, airports and electricity transmission grids. In fact, as of November 2014, the Protocol has been or is being used for more than 40 risk evaluations in Canada as shown in Figure 7, and two have been completed abroad. There are no known limitations to the type of infrastructure the Protocol can be applied to. It has been used both by small (e.g., District of Shelburne, NS – population about 3,000) and large (Toronto, ON) municipalities across Canada.

The Protocol is a five-step process that systematically reviews historical climate information and projects the nature, severity and probability 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, changes to operational or maintenance procedures.

The following list illustrates some of the Protocol assessment projects completed to date:

- City of Portage la Prairie – water supply and treatment infrastructure
- Town of Placentia, Newfoundland, coastal water control infrastructure
- Metro Vancouver – Vancouver sewerage area collection and treatment infrastructure vulnerability
- City of Greater Sudbury – city-wide roads and associated structures (bridges and culverts)
- City of Edmonton – Quesnell bridge and roadway infrastructure
- Government of Northwest Territories – building foundation infrastructure using thermosyphons
- Government of Canada office/laboratory building campus, Tunney's Pasture Ottawa, building infrastructure vulnerability

Figure 7: Locations and Type of Protocol Vulnerability Assessments Completed or in Progress as of February 2013

Examples of key vulnerabilities and recommended remedial actions from these assessments included:

- In the Metro Vancouver sewerage area, the trunk sewer, interceptors and sanitary mains are vulnerable to increased frequency and magnitude of intense rain events. These results have led to more intensive engineering investigations by the city.
- In Placentia Newfoundland, the coastal structures are vulnerable to the combination of increased storm surge combined with high tides and intense rain events.
- Storm water and wastewater as well as water treatment systems are vulnerable to interruptions in power supply resulting from climate change impacts e.g. severe weather events that may be local or located some distance away. Ensuring access to appropriate standby power is the recommended remedial action.
- Roads and bridges in Sudbury and the Quesnell Bridge are highly vulnerable to increased ice accretion and freeze-thaw cycles that will accelerate wear and tear. Heavier snows in Sudbury will require adjustments to snow removal procedures.
- The external cladding on Ottawa Tunney's Pasture buildings has high vulnerability to changes in the intensity and frequency of snow and wind events.
- Virtually all the infrastructure components that are highly vulnerable are due to increased frequency and severity of severe weather events. Better methods to track, predict and broadcast such events at local scales are needed.

Engineers Canada has 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.

3 CONCLUSION

While all the tools reviewed here provide value information for engineers, asset managers and decision-makers, the PIEVC Protocol has the engineering depth and breadth of application to help communities large and small adapt to a changing climate. The methodologies developed for risk assessments and climate change adaptation planning in the United States, Europe and Australia are all valuable, but may not be as affordable and timely as the PIEVC Protocol in engaging engineers who must work closely with other professionals to support the planning, operation, maintenance, management and use the infrastructure to benefit society. The results inform decision-makers to a level that is adequate 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.

4 ACKNOWLEDGEMENTS

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