



26-29 May 2021

THE PIEVC PROTOCOL FOR ASSESSING PUBLIC INFRASTRUCTURE VULNERABILITY TO CLIMATE CHANGE IMPACTS: NATIONAL AND INTERNATIONAL APPLICATION

Sandink, D^{1,2}, Lapp, D^{1,3}

¹ Institute for Catastrophic Loss Reduction, Canada

² dsandink@iclr.org

³ dlapp@iclr.org

Abstract: The Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol was developed by Engineers Canada in partnership with Natural Resources Canada (NRCan), between 2005 and 2012. The PIEVC Protocol is a structured, rigorous qualitative process to assess the risks and vulnerabilities of individual infrastructures or infrastructure systems to current and future extreme weather events and climatic changes. It has been used to assess various types and scales of infrastructure in Canada as well as Costa Rica, Honduras, Brazil, Vietnam and the Nile Basin. More than 100 assessments have been completed and others are underway. An important component of the PIEVC Program is the “Project Assessment Report” that presents the results of the application of the PIEVC Protocol, including conclusions and recommendations for climate adaptation actions to improve climate resilience. The types of recommendations include not only engineering-related to design, operations and maintenance, but also extend to health and safety, policy, procedural and management actions including more in depth study and analysis of particular risks or engineering vulnerabilities.

1. INTRODUCTION

The rate of climate warming in Canada is twice that of the global average, with faster rates of warming in Canada’s arctic regions (Bush and Lemmen, 2019). Climate change impacts, including changing temperature and precipitation regimes and increasing frequency of extreme events, present a significant risk to the built environment across the country (Bush and Lemmen, 2019; ECCC, 2016). Already climate-related hazards and disaster events represent a significant disruption to critical services provided by buildings and infrastructure in Canada. For example, disaster events driven by a combination of flood, hail, high wind, and wildland-urban interface fire resulted in ~\$11 billion in insured losses in Canada from 2015-2019 (CatIQ, 2021). These damages were largely attributed to impacts on residential and commercial property. Significant uninsured losses attributed to the above hazards include most coastal and river flood damage, interruptions in critical services, societal impacts caused by displacement during and after disaster events, and a multitude of additional social, environmental and cultural effects of disasters are not represented in disaster loss figures (see, for example, Porter et al., 2021).

Responding to historical climate events and potential future impacts of climate change, infrastructure and asset owners have increasingly worked to develop and apply formalized processes to account for the potential impacts of climate change on built, natural, and human systems (CCME, 2021; Debortoli et al. 2018; Infrastructure Canada, 2019; Ordonez and Duinker, 2015; Naylor et al., 2020). Further, given the role of the engineering community in designing, managing and operating infrastructure, the engineering community can make critical contributions with respect to understanding and managing these risks, and ultimately offering evidence-based risk management policy recommendations under changing climate conditions (Dixon, 2009). The PIEVC Protocol was developed by Engineers Canada with the support of NRCan as a tool to identify inherent risks of failure or damage to infrastructure systems associated with climate change and climate-related hazards. It was developed to meet the needs and professional

obligations of engineers to identify and address climate impacts through climate consideration in professional practice (Lapp, 2005).

The PIEVC process assesses the negative impacts of extreme weather and changing climate to physical infrastructure and its operation, and assists infrastructure decision makers in managing uncertainty associated with future climate change impacts. The scope of assessments includes the impact of the loss or damage that infrastructure would have on societal and worker health and safety, and economic, social and environmental factors of concern to the public served by the infrastructures. The Protocol was designed to assess all types and scales of civil infrastructures including buildings.

The Protocol uses the best information available for “project assessments” including design parameters, operational and maintenance data that include performance records from past severe climate events. It requires climate data and future projections of climate parameters provided by climate scientists/specialists and often delivered through nationally or regionally based climate services. It includes the engagement of infrastructure operators and maintenance staff who have intimate knowledge of the infrastructure and memories of impacts and corrective actions undertaken at the time to minimize the impacts of a climate event. This human element and engagement is critical to a credible and defensible assessment.

A multi-disciplinary, multi-stakeholder team is needed to assure a fulsome assessment. The team can be customized to focus on the priorities of the owner, but would normally include engineers (of one or more disciplines depending on the type of infrastructure), climate scientists, representatives of the infrastructure owner (such as risk manager, operator(s)) and other stakeholders (e.g. planners, managers, emergency response, decision and policy makers, natural scientists) as required. It is a highly collaborative and iterative process that depends on the collective expertise, experience and perspective of these experts and stakeholders.

Further to the above, the Protocol supports “mixed methods” with respect to climate vulnerability assessment for infrastructure and buildings (CCME, 2021). Vulnerability assessments conducted using the PIEVC Protocol typically rely on both quantitative and qualitative data and the process can be adjusted to reflect data and expertise available for any given assessment. Further, the processes may be applied as either a “top-down,” screening or narrow-scope assessment driven and completed by a small team of experts, or as a “bottom-up” approach, relying on insights and consensus drawn from a range of experts through facilitated workshops.

The Protocol’s ability to facilitate top-down assessments is exemplified by its wide use to support “climate lens” and screening assessments (see for example Wood, 2021). Conversely, “bottom-up” assessments include those that rely on input gained from multiple stakeholder engagement workshops. Workshops may include systematic collection of input from a wide variety of infrastructure stakeholders, from political decision makers to operations staff with an equal say in workshop decision processes (see for example RDH Building Science, 2018, where building operators to medical practitioners were engaged in assessment workshops of a hospital building). Further, the Protocol may be applied for specific, highly localised infrastructures (see, for example Prism Engineering, 2020 – an airport assessment), as well as assessment for a variety of infrastructure types for extremely large geographic areas (see, for example, WSP, 2021 – an assessment of multiple infrastructure types across the whole of the Northwest Territories).

2. THE PIEVC PROTOCOL

Engineers Canada began development of the PIEVC Protocol in 2005 in partnership with, and co-funding from NRCan. It involved the formation of technical and strategic guidance committees, comprised of a cross section of infrastructure and climate experts, federal, provincial, municipal government representatives, local utilities, various infrastructure owners, academics, standards organizations, and several non-government organizations involved in climate change adaptation. The development included an extended period of validation and refinement through the execution of case studies and a “learn by

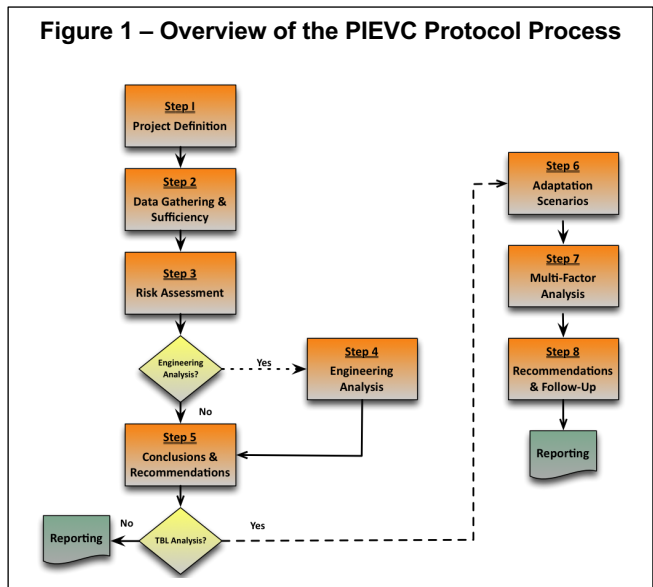
doing” approach across a wide variety of infrastructure types and types of owners – from large cities to small communities. The development was completed in 2012 with publication of Version 9 and the end of co-funding support from NRCan. The PIEVC Protocol was incorporated into an ongoing program (the “PIEVC Program”) operated by Engineers Canada until 2020 when it was divested to a partnership including the Institute for Catastrophic Loss Reduction (ICLR), the Climate Risk Institute (CRI) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (the PIEVC Program Partnership).

The Protocol is a qualitative risk identification and assessment process that defines climate risks and vulnerabilities at a screening level. It is adopted from CAN/CSA Standard Q850-97 (R2009) Risk Management: Guideline for Decision-Makers (CSA, 2009). Unlike quantitative risk tools, it does not require comprehensive nor complete data to undertake an assessment. The trade-off is that it does not provide quantitative estimates of risk, but rather “risk scores” that can be ranked into levels of risk, qualitatively described (and defined) with terms such as high, medium and low risk. It provides a high level understanding of climate risks that is often sufficient to support adaptation and resilience decision-making, especially for smaller infrastructures and for small communities. It can also inform more detailed quantitative risk assessments and help focus these types of studies on the key issues that may need deeper, more quantitative analysis before decisions can be made on action and budget allocation.

Through the PIEVC Protocol process, “infrastructure” is defined as a series of structural and non-structural components. Structural components are normally the physical sub-systems that are assembled to enable the infrastructure to operate – for example foundation, building envelop, roof, electrical and mechanical systems for buildings. Non-structural components include items such as the personnel that operate and maintain the infrastructure, policies and procedures as well as codes and standards, and local regulation. An additional layer of component definition concerns the users of the infrastructure and/or the external suppliers of services to the infrastructure (e.g., utilities).

Each of these components interacts with, or is affected by, climate in varying ways and to varying degrees. Some components will only be affected or interact with certain climate elements. Understanding infrastructure component/climate interactions is a key element of the analysis. A further key element of the Protocol process is identifying the appropriate level of component definition. The more components that are defined, the larger the scope of effort to identify the climate-component interactions followed by the analysis of risk for each one. Normally components are defined at a system or sub-system level since further granularity does not provide additional insight for the level of effort required.

The scoping of the risk and vulnerability assessment is scalable in that the breadth and depth of the component definition can be limited. Scaling will affect what information is required and who should be involved. Ideally the stakeholders that should be at the table would represent or support all of the structural and non-structural elements of the infrastructure. However, in normal practice this is not always possible nor practical and it may not serve the interests of the infrastructure owner. It is important however to record components or stakeholders which were not considered, or who did not participate, and to include these limitations in the final assessment report.



2.1 The PIEVC Protocol Steps Explained

Figure 1 and Table 1 summarize the basic tasks within each step in the process. Preparation is key to a successful assessment with useable outcomes. Preparation includes understanding the type and location of infrastructure that is to be assessed. Step 1 requires the project parameters to be refined and adjusted to meet constraints such as budget, time and the detail needed from the assessment. The more components that are identified for assessment, the greater the depth and breadth of data compilation and analysis, with additional time and budget likely required. With respect to stakeholder engagement, many PIEVC assessments have organized a workshop of key stakeholders to achieve consensus on project definition while others have used interviews. The aim is gain a shared understanding and agreement of the scope to manage expectations and execution.

Step 2 requires working with the infrastructure owner/management as well as operations and maintenance personnel to secure items such as drawings, operational records, local codes, standards, jurisdictional constraints and so forth. The availability of local historical climate data and climate projections is another significant task that requires a climate specialist. Interviews with management and operational personnel are sometimes used in data and information collection. Understanding the condition of and where an infrastructure is in its life cycle is fundamental to the process.

In every assessment there are data gaps or missing information that must be supplemented by local knowledge and consultations with operations and maintenance personnel. Data gaps, either climate or infrastructure, can be augmented by the experience and professional judgment of the assessment team members working with the infrastructure owner and their operations/maintenance personnel. Ideally these consultations and judgments are combined with, and informed by, a site visit.

Step 3 is normally carried out through one or more workshops where the stakeholders are brought together to define and score the consequences of exceeded climate thresholds. The climate specialist should have determined the likelihood score in advance so the focus of workshops is on consequences. Consequence scores are determined by consensus or voting procedures. The consequence scores are multiplied by the climate likelihood score to produce a climate risk score. The results are normally tabulated in a risk matrix – one for current climate and one for the future climate as a means to document results. The difference in the current and future climate score is the increase or decrease in risk attributed to climate change. Of greatest concern are increases in risk scores from current to future climate especially where the risk level is shifted into the range that is considered high. High risk interactions require earlier and possibly immediate adaptation action.

Step 4 - Engineering Analysis is an optional step in the process. The analysis is complex and requires more engineering data on capacity and loading that may be limited or not available in some cases, and is limited to a few cases where the infrastructure component is critical to the integrity or operation of the infrastructure.

Once the risk is identified, adaptation solutions are normally developed to address the high and medium level risks. These can be structural actions that involve “grey” solutions, nature-based solutions, or a combination of both. “Non-structural” actions are part of the suite of adaptation solutions and may include changes to policies or procedures. The actions may include timelines and estimated costs. It should be noted that within an assessment all system elements including physical built systems, interconnected systems (e.g., power supply to water distribution), management, personnel, operational and maintenance procedures can be included or not included. Thus, the PIEVC Protocol is a scalable process.

Table 1: PIEVC Steps and Main Tasks

Step	Description	Main tasks
-	Preparation	<ul style="list-style-type: none"> • Identify infrastructure for assessment (existing or new) • Determine scope of assessment, including budget, timeline, and participants • Assemble Project Assessment Team (owner and consultant, if applicable)
1	Project Definition	<ul style="list-style-type: none"> • Define structural and non-structural infrastructure components • Define climate parameters of interest/concern • Define future climate period(s) of interest – tie to infrastructure life cycle • Define geographic location and boundaries • Determine risk levels and scoring (e.g., three, five or seven levels – defined by owner and consultant) • Determine high, medium and low risk scores
2	Data Collection, Compilation and Analysis	<ul style="list-style-type: none"> • Define climate parameter thresholds that would include component failure • Compilation and analysis of historical climate data to determine probability of threshold exceedance and conversion to a likelihood score • Utilize climate projection models to determine probability of exceedance in future climate period of interest • Assemble infrastructure component information (design drawings, age, condition assessments, operational records (if available))
3	Risk Assessment	<ul style="list-style-type: none"> • Conduct a Yes/No Analysis – is there an interaction with/between the component and climate parameter(?) • Determine probability/likelihood score for exceedance of climate thresholds, for current and future climate • Determine the consequence score for a component climate parameter interaction, given that there is an interaction and that the climate threshold has been exceeded • Calculate the risk score for all climate/component interactions • Classify risk scores into risk levels to develop a current and future climate risk profile
4	Engineering Analysis (optional)	<ul style="list-style-type: none"> • Analysis of climate loads and component capacity on selected structure components to determine vulnerability
5	Conclusions and Recommendations	<ul style="list-style-type: none"> • Describe risk profile (climate parameter/component interactions classified into risk levels – e.g., high, medium, low) • Identify high risk interactions for early action, medium for future action, low for monitoring • Develop recommended adaptation actions to reduce risk levels
-	Reporting	<ul style="list-style-type: none"> • Complete Project Assessment Report • Document all executed steps, include risk matrix or risk profile for current and future climate • Disclose limitations, gaps, unknowns

2.2 The PIEVC High Level Screening Guide

Long term use of the PIEVC Protocol has demonstrated that full applications of the Protocol generally require considerable resourcing and time to complete. Further, in specific cases, more streamlined approaches would provide a level of information more suitable to the particular phase of an infrastructure's life cycle, prove more cost and time efficient, and still be highly technically defensible.

The Protocol was originally developed for comprehensive screening-level assessments of existing assets. Though the Protocol has since been used on various occasions to assess projects still in their planning or design phases, it was not originally established with this particular use in mind. Considerably more attention is now placed on screening-level assessments of the climate vulnerability and related risks of *projects in their pre-planning (project identification) and planning phases*. From a Canadian perspective, the Federal Climate Lens has been an especially important driver of this type of assessment.

To better support practitioners conducting the resiliency portion of Climate Lens assessments, other such assessments focused on the project identification or planning phases of a new asset, as well as rapid assessments of one or more (e.g. a portfolio) of existing assets, the PIEVC Protocol needs to be modified. Numerous stakeholders have called for the development of a new, supplemental version of the PIEVC Protocol, better aligned with screening-level climate vulnerability and risk assessments conducted during the planning phase of proposed infrastructure projects. This new version has been referred to as “PIEVC High Level Screening Guide.” This new version of the PIEVC Protocol is currently in development and will be available in the latter half of 2021.

3. PIEVC PROTOCOL APPLICATIONS

3.1 Application in Canada

Table 2 provides a summary of completed and in progress assessments by infrastructure category. The Protocol has been applied to several types of linear infrastructures e.g. roads and highways, as well as for infrastructures at a specific location. Most of the reports from these assessments are publicly available at the website www.pievc.ca, operated and maintained by ICLR as part of the PIEVC Program. Some reports are not included for reasons of confidentiality on the request of the infrastructure owner. This collection of assessment reports provides valuable references to inform the planning and execution of future assessments as well as for research purposes. For example, the reports could be used to determine the need and provide evidence for adjustments to infrastructure codes, standards and related instruments.

Owners of these infrastructures are from all three levels of government in Canada and, at the municipal level, from small communities with populations in the thousands to Canada’s largest cities. A majority of the completed assessments are for existing infrastructures. The recommendations from these assessments center primarily on adjustments to operations and maintenance procedures and policies including worker health and safety in times of extended high heat or more intense storms. An example of recommendations related to operations is seen in the assessment of the G. Ross Lord and Claireville water retention dams operated by the Toronto and Region Conservation Authority (Bourgeois et al., 2010).

An additional example of an operational adjustment resulting from a PIEVC assessment includes a change in the frequency and nature of inspection of more than 300 large culverts in the City of Toronto following an assessment of the climate risks and vulnerabilities to three representative culvert types installed by the city. The impetus for the assessment was the failure of a culvert crossing Finch Avenue from an intense localized rainfall in August 2005. The PIEVC assessment provided the evidence to justify the changes in procedure, and to improve the climate resiliency of Toronto culverts to extreme rainfall events in the future (Genivar Inc., 2011).

The Municipality of the District of Shelburne, Nova Scotia sought to upgrade and expand their existing sewage treatment plant. The municipality included a climate risk and vulnerability assessment task as part of the design contract. The assessment influenced the location of the expansion relative to the coast to accommodate future as well as the selection of treatment technologies (ABL Environmental Consultants Ltd., 2011).

Table 2: Canadian PIEVC Assessments by Category of Infrastructure

Infrastructure category	Number of completed assessments*	Number of assessments in progress*
Buildings (all types)	23	2
Water supply and treatment	4	2
Stormwater and wastewater collection, treatment and conveyance	18	4
Roads, highways, bridges and associated structures	12	1
Urban transit systems	1	1
Coastal infrastructures and ports	13	4
Airports	7	2
Utilities (e.g., power distribution)	5	1
Indigenous/First Nations	8	4
Other, including screening of assets across a large geographic region	1	1

*These figures do not include all uses of the PIEVC Protocol for Infrastructure Canada's Climate Lens requirement.

The Protocol was used to evaluate the climate risks and vulnerabilities for a conceptual design of an extension to an engineering building at the University of Saskatchewan. The results of the assessment triggered adjustments to the design to accommodate future climate risks from higher temperatures as well as increased frequency and intensity of storm water events (Associated Engineering (Sask.) Ltd., 2012). These are a few examples of the application of the PIEVC Protocol and how the results influenced or triggered adaptation actions to improve climate resilience.

In 2016, Engineers Canada was approached by the Ontario First Nations Technical Services Corporation (OFNTSC) to explore the application of the PIEVC Protocol to First Nations (FN) infrastructure in Ontario. The PIEVC Protocol was used to assess the potable water supply system for the Akwesasne First Nation located near Cornwall Ontario (Stantec/OFNTSC, 2017). The pilot study was intended to demonstrate the utility of the Protocol for FN infrastructure systems. The Protocol was subsequently applied in two other case studies - Moose Factory (example of a remote northern community) and Oneida First Nation (example of a southern community) (Stantec/OFNTSC, 2018a, b).

The success of these projects led to the development of a variant to the PIEVC Protocol that was referred to as the PIEVC FN Protocol. Further development by OFNTSC with financial support from the federal government enabled the development of an Asset Management module that is integrated with the PIEVC FN Protocol to create the FN (PIEVC) Asset Management Toolkit. Since this development the OFNTSC has conducted an extensive training program among almost all FN communities in Ontario. Efforts are underway to offer the Toolkit to other FN communities outside of Ontario and two further PIEVC assessment one in Saskatchewan and the other in Quebec are nearing completion at the time of writing.

3.2 International Applications

Through its participation in the World Federation of Engineering Organizations (WFEO), and encouragement and funding support from NRCan and Environment Canada (now Environment and Climate Change Canada), Engineers Canada was able to engage with national engineering organizations in Costa Rica and Honduras to conduct PIEVC assessments for infrastructures located in these countries. Following these first two projects, Engineers Canada continued its international promotion of the PIEVC Protocol, organizing workshops and side events at UNFCCC COP and intersessional meetings. It was at these meetings that an interest was sparked with GIZ which eventually led to collaboration on the GIZ "Climate Services for Infrastructure Investment" (CSI) project. A component of the project was the application of the Protocol in three countries and the Nile Basin for projects listed in Table 3.

Table 3: International PIEVC Assessments by Country

Project location	Year	Type of infrastructure assessed
City of Limon, Costa Rica	2010-2011	Stormwater and wastewater Four road bridges
Road Bridges, Honduras	2013-2014	
Guanacaste Province, Costa Rica	2017 to present	Regional water supply
Mekong Delta, Vietnam	2018-2019	Sluice gates
Mekong Delta, Vietnam	2020-2021	Update and further assessment of multiple small scale sluice gates
Itaaji Port, Brazil	2018-2020	Port facilities
Electrosul Hydro Authority, Brazil	2018-2020	Transmission lines
Nile Basin	2018-2020	Hydro-electric and water control dams

4. The PIEVC Partnership and the PIEVC Program

In 2019-2020, Engineers Canada conducted a divestment process for the PIEVC Protocol and associated PIEVC Program elements. The process involved inviting a small group of non-profit associations to submit proposals to assume the full PIEVC Program. A total of seven organizations were invited to submit bids. A partnership involving ICLR, CRI and GIZ submitted a bid and were awarded the program and assumed ownership in March 2020.

The objective of the “PIEVC Program Partnership” is to maintain and expand the PIEVC Program, while maintaining its primary tenants of free Protocol access for public infrastructure applications in Canada and ensuring that, to the extent possible, PIEVC Protocol assessment reports remain publicly accessible via the www.pievc.ca website. ICLR and CRI will provide administrative and technical support for the PIEVC Program in Canada, while GIZ will focus on continued international implementation of the PIEVC Protocol.

Under the partnership, the guiding principles and objectives of the PIEVC Program include:

- Providing freely accessible, open, credible resources to support improved understanding of the impacts of climate change on Canada’s infrastructure and buildings.
- Providing a Community of Practice to engage and work directly with infrastructure policy and decision-makers from the public and private sectors.
- Improving the understanding, capacity and expertise of policy makers, decision makers, infrastructure professionals and practitioners to adapt infrastructure based on current and future climate risks and vulnerabilities.
- Providing ongoing advice to, and engagement with, governments, and other regulatory authorities on reviews and adjustments to infrastructure codes standards and related instruments to account for and mitigate climate risks and vulnerabilities.

Training for PIEVC Protocol practitioners is available as part of a parallel program to the PIEVC Program - the Infrastructure Resilience Professional (IRP) program. This program includes a series of courses that lead to an “IRP” credential, and includes a course focussed on the PIEVC Protocol.

Publication of PIEVC Protocol assessment reports is considered the primary “public good” of the program, and is intended to facilitate increased application of infrastructure climate change vulnerability assessment methods nationally and internationally, as well as facilitate academic research, policy discussions and strategic climate change adaptation initiatives at all levels of government and in private industry, both in Canada and internationally. Each user of the PIEVC Protocol is requested to complete a licence agreement, which includes a condition that a final assessment report is submitted to the PIEVC Program Partnership. Reports are placed on the www.pievc.ca website for public access. Publication exceptions have been made in several instances where assessment reports contain confidential information.

5. Conclusion

The PIEVC Protocol is a nationally recognized tool for the assessment of climate risks and vulnerabilities for public infrastructure in Canada. It has been applied to a wide variety of infrastructures and a community of practice is developing among practitioners as well as owners. It is a “Made in Canada” tool for the highly specialized and focused task of infrastructure climate risk and vulnerability assessment to inform climate adaptation decision-making and the subsequent actions to reduce risks and improve the climate resilience of the infrastructure.

The development and application of the PIEVC Protocol by engineers working with other practitioners and stakeholders has provided a practical means to assess risk and determine structural and non-structural adaptation actions to improve climate resilience. The fact that the Protocol has been applied to a wide variety and scale of infrastructures, through both top-down and bottom-up applications, demonstrates its versatility, flexibility and practicality. The process fosters collaboration among a wide cross-section of professional and scientific disciplines working with the managers, operators and maintainers of the infrastructure, which is one of its greatest strengths.

6. Acknowledgements

The authors wish to acknowledge ICLR, CRI and GIZ for their support of the PIEVC Program. We would also acknowledge the leadership of Engineers Canada who initiated, and contributed extensive resources during the development and operating stages of the Program. We further acknowledge NRCan for their partnership and encouragement during the development years and their many years of ongoing support.

7. References

ABL Environmental Consultants Ltd. 2011. Vulnerability of Sandy Point STP Upgrade to Climate Change. Prepared for the Municipality of the District of Shelburne. Available via www.pievc.ca.

Associated Engineering (Sask.) Ltd. 2012. University of Saskatchewan Assessment of the Engineering Building's Vulnerability to Climate Change. Available via www.pievc.ca.

Bourgeois, G, Dickson, S, Ness, R, and Lapp, D. 2010. Is your dam vulnerable to climate change? Using the PIEVC engineering protocol. *Proceedings of the Canadian Dam Association Conference 2010: partnering for a safer future*, (p. 175). Canada: Canadian Dam Association.

Bush, E. and Lemmen, D.S., editors. 2019. Canada's Changing Climate Report. Ottawa: Government of Canada.

Canadian Council of Ministers of the Environment. 2021. Guidance on good Practices in Climate Change Risk Assessment. Canadian Council of Ministers of the Environment.

Canadian Standards Association 2009. Risk Management: Guideline for Decision-Makers CAN/CSA Q850-97 (R2009) <https://www.scc.ca/en/standardsdb/standards/6777>

Debortoli, N. S., Sayles, J. S., Clark, D. G., & Ford, J. D. 2018. A systems network approach for climate change vulnerability assessment. *Environmental Research Letters*, 13(10), 104019.

CatIQ. 2021. Disaster Bulletins. Toronto: CatIQ. Accessed May 2021 from catiq.com.

Dixon, M. 2009. Climate change, politics and the civil engineering profession. *Proceedings of the Institution of Civil Engineers-Municipal Engineer*, 162(4), 207-210.

Engineers Canada 2008. Adapting to Climate Change: Canada's First National Engineering Assessment Report See: http://www.pievc.ca/e/doc_list.cfm?dsid=4

ECCC. 2016. The Public Infrastructure Engineering Vulnerability Committee Protocol, Version 10. Toronto/Ottawa: PIEVC Program Partnership.

Government of Canada. 2016. Pan Canadian Framework on Clean Growth and Climate Change: Canada's Plan to Address Climate Change and Grow the Economy. Ottawa: Environment and Climate Change Canada.

Infrastructure Canada. 2019. Climate Lens – General Guidance. Ottawa: Infrastructure Canada. Accessed May 2021 from <https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html>

Lapp, D. 2005. What Engineers Should Know About Climate Change. *PEO Engineering Dimensions*, March April 2005 pp51-53.

McConnach J.S., Zobaa, A.F. and Lapp, D. 2011. Impacts of Climate Change on the Power Industry and How It is Adapting. In Mcconnach, J., and Zobaa, A. (eds). *Climate Change - Research and Technology for Adaptation and Mitigation*.

Genivar Inc. 2011. Climate Change Vulnerability Assessment for Culverts. Prepared for the City of Toronto. Available via www.pievc.ca.

Naylor, A., Ford, J., Pearce, T., & Van Alstine, J. 2020. Conceptualizing climate vulnerability in complex adaptive systems. *One Earth*, 2(5), 444-454.

Ordóñez, C., & Duinker, P. N. 2015. Climate change vulnerability assessment of the urban forest in three Canadian cities. *Climatic change*, 131(4), 531-543.

Porter, K.A., Scawthorn, C.R., and Sandink, D. 2021. An Impact Analysis for the National Guide for Wildland-Urban Interface Fires. Prepared for the National Research Council of Canada. Institute for Catastrophic Loss Reduction, Toronto, ON, 136 p.

Prism Engineering. 2020. Penticton Airport Climate Change Risk Assessment Report. Burnaby: Prism Engineering. Prepared for Transport Canada & Public Service and Procurement Canada (PSPC). Available via pievc.ca.

RDH Building Science. 2018. Nanaimo Regional General Hospital Vulnerability Assessment Report. RDH Building Science. Available via pievc.ca.

Stantec/OFNTSC. 2018a. Climate Change Impacts on the Housing Infrastructure at Oneida Nation of the Thames. Ontario First Nations Technical Services Corporation. Available via pievc.ca.

Stantec/OFNTSC. 2018b. Climate Change Impacts on Water and Wastewater Infrastructure at Moose Factory. Ontario First Nations Technical Services Corporation. Available via pievc.ca.

Stantec/OFNTSC. 2017. Climate Change Impacts on Water and Wastewater Infrastructure at Akwesasne. Ontario First Nations Technical Services Corporation. Available via pievc.ca.

Wood. 2021. Climate Lens Assessment: G.H. Daw Community Centre Enhancements. Prepared for the City of Red Deer. Available via pievc.ca.

WSP. 2021. Government of Northwest Territories Assessment of Climate Change Impacts on Infrastructure in All NWT Communities. Prepared for Government of Northwest Territories. Montreal: WSP Canada Inc. Available via pievc.ca.