Canada's Climate Change Adaptation Platform

*Equipping Canadians for a Changing Climate*

# Infrastructure and Buildings Working Group

# Adaptation State of Play Report

## March 2017

**Infrastructure and Buildings Working Group – Adaptation State of Play Report**
Prepared for: Natural Resources Canada, Climate Change Impacts and Adaptation Division
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# Disclaimer

This State of Play Report was commissioned to provide an overview of the state of adaptation in Canada and the activities underway in the infrastructure and building sectors and to identify gaps and opportunities and potential options for addressing them.

This report will inform the work of Canada's Climate Change Adaptation Platform[1] Infrastructure and Buildings Working Group, and serves as one of many sources of input to Working Group discussions on their work plan for the next four (4) years.

Inclusion of information in this document should not be considered as endorsement by members nor their organizations. Working Group members assume no responsibility for errors or omissions in the content.

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[1] http://www.nrcan.gc.ca/environment/impacts-adaptation/adaptation-platform/10027

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# National Infrastructure and Buildings Climate Change Adaptation State of Play Report


| | |
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All recommendations, omissions and remaining errors are solely those of the authors and may not be attributed to any of the people mentioned above.

# Executive Summary

The Infrastructure and Buildings Working Group (IBWG) was established by the Institute for Catastrophic Loss Reduction (ICLR) and Engineers Canada, in consultation with Natural Resources Canada, in 2013 and is part of Canada's Adaptation Platform. The IBWG's purpose is to build capacity, generate evidence and provide outreach to increase the capability of infrastructure managers, municipalities, builders, insurers, engineers and other relevant stakeholders to adapt and facilitate adaptation to climate change. The IBWG is comprised of federal, provincial, private industry and non-government representatives working in the field of climate change adaptation and disaster risk reduction.

The Infrastructure and Buildings Adaptation "State of Play" project provides an overview of state of adaptation in Canada and the activities underway in the infrastructure and building sectors. The project has drawn on input from a variety of key infrastructure and adaptation experts in Canada, literature reviews, includes input from the IBWG. Various gaps and opportunities have been identified as well as potential options for addressing them. Amec Foster Wheeler and Credit Valley Conservation have been leading the project. This report is intended to inform the work of Canada's Climate Change Adaptation Platform IBWG, and serves as one of many sources of input to Working Group discussions on their work plan for the next four (4) years.

Vulnerability assessments have been carried out across Canada that have demonstrated the potential risks to Canada's infrastructure systems, and thereby, to the communities served by those systems. Rising temperatures, altered hydrological conditions, and more frequent extreme weather events all pose a risk to Canada's water, building, transportation, information, communications and other infrastructure.

A variety of factors influence the level of risk associated with future climate change. Some Canadian communities that were built prior to today's standards do not have contemporary forms of stormwater management; the result is a risk to flooding under today's climate, with future climate change only exacerbating the issue. Historical stormwater infrastructure systems have not been designed to be resilient to climate risks such as flooding. However, these systems have been rated as in *good* condition by federal benchmarking studies, which have only considered age and condition, rather than the ability of those systems to provide modern, widely accepted levels of service. Other infrastructure, like drinking water systems, have been designed to provide an adequate level of service to the communities they serve under today's climate conditions, but may not continue to do so in the future.

In many circumstances, interconnections between types of infrastructure support the production and distribution of goods and economic services. Overall, there are many interdependencies between the infrastructure sectors and failure in one area can quickly lead to a cascade failure affecting other systems. Many components of infrastructure are often co-located (e.g. power cables laid below roads and beside communications cables, adjacent to water and gas mains and sewers), especially in urban areas (i.e. roadway right-of-ways). An extreme rainfall event on August 19, 2005 in Toronto had many negative impacts, including flood damage to thousands of homes and roughly $740 million in insured losses (2015 CAD). The failure of the Finch Avenue roadway embankment and culvert during this event, an arterial thoroughfare in North York, affected both the roadway and co-located infrastructure, including gas mains, water mains, sanitary sewer, telecommunications and recreation infrastructure. The Finch Avenue failure highlighted how the failure of one infrastructure system can severely impact others.

Events such as the 2013 Alberta and Greater Toronto Area floods, and other extreme weather events, have demonstrated the vulnerability of infrastructure. Many municipalities and senior levels of government that have recognized their infrastructure's vulnerability to climatic events and to future climate change and have begun taking steps to improve the resiliency of their infrastructure through adaptation actions.

Climate risks to Canada's buildings and infrastructure reaches beyond the systems themselves. The July 8, 2013 storm in Toronto was linked to approximately $1 billion in damages (2015 CAD), but climatic events have other social costs as well often overlooked in the accounting of impacts. When important public infrastructure, such as drinking water, hospitals, schools and roadways are impacted by climatic events, it is often the most vulnerable members of the community who bear the brunt of the impact.

The principal objective of this study has been to identify the current state of climate change adaptation actions across Canada focussed on improving resiliency of infrastructure systems, with an emphasis on the following themes:

- Water Infrastructure
  - *Stormwater Infrastructure*
  - *Wastewater Infrastructure*
  - *Drinking Water Systems*
  - *Watersheds*
- Transportation Systems
- Engineered Buildings
  - *Residential*
  - *Hospitals*
  - *Correctional Facilities*
- Non-Engineered Buildings (as defined in Part IX of the National Building Code of Canada)
- Other Infrastructure
  - *Telecommunications*

The study has emphasized the impact of adaptation actions on public and community services, and the people who depend on them.

The key challenges in adaptation planning are the uncertainty of climate change events and the unforeseen impacts resulting from them. Adaptation to climate change will require modifications in planning and design approaches for infrastructure and buildings to address the increasingly extreme and volatile climate, with focus on some important areas such as:

- Development of guidelines, codes, standards, specifications, etc. that take into consideration the expected climate change impacts.
- Development of critical infrastructure inventories including the evaluation of vulnerabilities and identification of priority at-risk areas, based on the projected impact due to climate change.

- Identification of areas of high risk based on recent events (e.g. new flood zone mapping).
- Completion of risk and cost benefit analyses on alternatives to support decision-making on priority adaptation actions.
- Review of strategies and standards being used by other organizations (perhaps in other geographies) that have current weather similar to what is expected (i.e., very hot places already have designs that are adapted to hot weather).
- Incorporation of area specific storms and other extreme weather events in the assessment of infrastructure and building vulnerability, including identification of possible adaptation measures based on risk assessment.
- Integration of planning and decision-making amongst departments within an organization or amongst stakeholders.

The development of comprehensive site-scale vulnerability assessments that incorporate the above concepts should also be promoted.

Barriers to climate change adaptation in Canada most frequently mentioned in the literature and in conversations with subject matter experts completed for this State of Play report were:

- Inconsistent and lack of climate change guidance and direction at the provincial and federal levels.
- Need for municipal direction on how to define a risk tolerance, particularly within existing urban areas.
- Need for municipal direction on how to set design goals for infrastructure to meet the needs of future climate within its lifespan.
- Lack of defined roles and responsibilities for water infrastructure creates confusion and lack of integrated adaptation strategies.
- Lack of engineering tools to support optimization of adaptation measures or the financial tools to make an effective business case for adaptation action for municipalities who have been proactive and have completed infrastructure risk assessments.
- Lack of funding to implement adaptation initiatives.
- Lack of streamlined climate change data resources to accelerate implementation.
- Lack of public awareness of climate change and the need for making adaptation changes now.

To address these barriers, a list of sixty-two (62) opportunities or next steps has been developed through this State of Play study as summarized in the following:

### All Governments, Organizations and Private Groups

- Assessment of potential infrastructure interdependencies with the view to identification of risks which left unaddressed in their sector/organization could become secondary risks to others and vice versa.
- Development of indicators to measure the success of adaptation measures or outcomes of adaptation policy.

- Development of asset inventories or frameworks for asset management given that having a proper inventory of existing assets and their condition is a necessary first step to integrating climate change adaptation considerations into infrastructure planning.
- Development of an outreach and engagement strategy to support the development of awareness of the availability and uptake of climate change adaptation guidelines, plans and protocols that are available.
- Development of goal-oriented policies and objective-based standards for decision-making.

### Federal

- Development of key policies, regulatory and financial tools, in partnership with Provinces and Territories, that include processes to enable the integration of climate change adaptation considerations into infrastructure decision-making, design and maintenance.
- Development of a unified approach to updating Intensity-Duration-Frequency (IDF) relationships, including projections, and design standards for stormwater management.
- Development of a one-window, unified, climate resource centre that provides the foundational information and access to climate data and information locally and regionally. The centre could provide open and equitable access to a variety of information including climate change, water, land and natural resources, transportation, as well as socioeconomic information. The climate resource centre could provide an opportunity for all adaptation experts from various disciplines to come together and help decision-makers and practitioners develop innovative responses to climate change impacts.
- Enhancement of investment in atmospheric, hydrometric, infrastructure and groundwater monitoring to enhance knowledge and understanding of these systems and how they interact.
- Development of a framework for dedicated funding for assessment of climate change risks/vulnerabilities, provision of consistent future data, updating flood maps and models, implementing infrastructure upgrades, and developing adaptation plans.
- Update of existing building codes and standards to incorporate climate change and advancements in climate knowledge and climate impacts such as costs and social disruption.
- Development of a sustainability and resiliency self-assessment rating system and report card for infrastructure and building systems.
- Development of performance monitoring and reporting guidelines, in partnership with Provinces and Territories, to identify future infrastructure needs in an effort to enhance communities and develop better systems in the future.
- Development of guidelines focused on resilient systems, which include adaptability to climate change and community growth, as well as recovery from extreme events.
- Development of quality management standards for stormwater and wastewater.
- Enhancement of risk-based prioritization tools to evaluate and prioritize infrastructure needs, to include consideration of social vulnerabilities.

- Development of standards to perform forensic accounting of extreme events in an effort to build a database that includes financial and service risks and costs.
- Development of an up-to-date infrastructure deficit estimate, in coordination with Provinces and Territories.

### Provincial

- Development of provincial regulations to incorporate climate change resiliency in new, existing and redevelopment areas.
- Development of clear guidance on how to interpret provincial policies that address climate change.
- Development of a one-window central repository for climate data including localized climate projections and provincially adopted future climate data sets.
- Development of goal-oriented approaches, as opposed to prescriptive approaches, for infrastructure sizing. Goal-oriented policies can be more quickly enacted, whereas updating guidelines/ standards is a slower process.
- Development of quality management standards for stormwater and wastewater infrastructure and provide the basis for political engagement, commitment and endorsement.
- Incentivization of source controls such as low impact development/green infrastructure to mitigate erosion impacts, promote groundwater recharge and support the implementation of water treatment technologies for nutrient removal.
- Development of a systems approach in managing drinking water, wastewater and stormwater systems that includes a watershed approach, as defined by integrated water resources management.
- Preservation and restoration of critical wetlands and other natural infrastructure.

### Municipal

- Dedication of budgets for capital and operations work related to climate change adaptation.
- Development of municipal/public partnerships to explore options for adaptation on private property.
- Incorporation of adaptation into municipal planning policy.
- Integration of planning, capital works, and emergency services to optimize investment and reduce risks to vulnerable populations.
- Development of standards for flood proofing of wastewater and water treatment plants, and other infrastructure and buildings, to address climate change risks (vulnerability to extreme rainfall or short duration and high intensity rainfall events).
- Development of standards for climate resilient chemical/materials management and storage in treatment facilities.

- Development of standards for drinking water infrastructure to support determination of chemical reserves, material process requirements and capacities to include the potential for increased water demand in drought conditions / consecutive dry days.
- Development of a standard for water conservation programs for municipalities.
- Development of better informed emergency management plans for infrastructure failures or extreme weather emergencies.
- Development of better coordination with regard to heat alert notifications. For example having water and wastewater operators ensure that proper cooling measures and back-up power generators are in place.
- Development of integrated asset management plans (operations and maintenance).
- Development of a risk-based prioritization tool with a variety of municipalities (sizes and location) to provide a standard approach for municipalities to evaluate and prioritize their infrastructure needs.
- Identification of learning needs and provision of necessary training to enhance municipal internal functionality and communications (i.e.: operations, engineering and finance groups).
- Development of terms of reference and on-going support for "peer-to-peer" communications amongst municipal groups for asset management planning and sustainability plans.
- Development of standardized practices guides for small communities adapting to extreme rainfall.
- Development of communication strategies and tools targeted to the public and elected officials to promote understanding and value of infrastructure and the need for investment to build resilient systems.
- Endorsement of water-related policies to ensure proper implementation at the municipal level. For example, in Ontario's Safe Drinking Water Act, municipal councillors are personally liable for their drinking water systems and to ensure that the appropriate actions are being taken to address potential climate change impacts.
- Build resilience into community access and transportation systems planning and development.
- Prioritization of areas of high climate change vulnerability/risk for implementation of adaptation measures.

### Private Companies (Insurance, Consulting, etc.)

- Inclusion of climate change and adaptation in professional training and education programs (e.g., design of green infrastructure as part of water resources engineering training).
- Development of an understanding of the risks and opportunities posed by climate change.
- Build climate resilience into corporate assets and decision-making.
- Encourage the use of data needed to make good decisions; if the company does not have all of the information needed, find ways to access it.

- Encourage long-term planning taking into consideration climate change.
- Encourage understanding of implications/risks of climate change to the business. These include disclosures by public companies due to regulatory obligations, increased shareholder interest and reporting issues. Climate Change and Related Disclosures will assist with education and awareness-building of mitigation, adaptation, and operational and financial impacts.
- Encourage the use of best practices and standards in corporate programs.
- Participation in the standards development process.
- Development of clear understanding of climate change reporting requirements.
- Better integration of climate change considerations into organizational planning, decision-making and risk management processes.
- Exercise due diligence as asset owners/operators and integrating climate considerations into asset management plans and infrastructure investment plans.
- Collaborate and engage across disciplines to enhance understanding of potential impacts and future changes on their assets and operations.

### Industry and Professional Associations

- Encourage membership to consider and support implementation of adaptation and mitigation actions.
- Provide training to membership with a goal to ensure that professionals can advise capably on adaptation. Consider making such training mandatory.
- Consider participation in the standards development process.

### Customers and Citizens

- Development of public awareness programs that increase knowledge of climate change and the need for adaptation.
- Consider participation in the standards development process.

While it has been recognized that actions advancing climate change adaptation are not consistent across Canada, some jurisdictions and organizations have been, and are, making advancements in these areas of opportunity.

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# 1.0 Introduction

Successfully planning for and managing the impacts of climate change requires not only the understanding of the risks and opportunities created by a changing climate but also information sharing and collaboration among multiple levels of stakeholders and decision-makers. The Climate Change Impacts and Adaptation Division (CCIAD) of Natural Resources Canada is leading the implementation of Canada's Adaptation Platform, which brings together national industry associations, national professional organizations, representatives from federal, provincial and territorial, and municipal governments, and other relevant organizations.

The multi-stakeholder Infrastructure and Buildings Working Group (IBWG) is part of Canada's Adaptation Platform. The IBWG was established in 2013 by the Institute for Catastrophic Loss Reduction (ICLR) and Engineers Canada, in consultation with Natural Resources Canada. The IBWG's purpose is to build capacity, generate evidence and provide outreach to increase the capability of infrastructure managers, municipalities, builders, insurers, engineers and other relevant stakeholders to adapt and facilitate adaptation to climate change. The IBWG is comprised of climate change adaptation stakeholders from federal and provincial governments, private industry and non-profits across Canada.

The objective of this State of Play report is to assist the IBWG to develop a common understanding of the current experience with climate change adaptation in the infrastructure and buildings sectors, including potential impacts, activities underway, and gaps and opportunities. The information presented in this report has been based on literature review, and input from the IBWG secretariat (comprised of staff from the Institute for Catastrophic Loss Reduction and Engineers Canada), IBWG members, and other industry experts.

The information in the document will provide a basis for IBWG discussions on the objectives and content of their program work plan for the next several years.

## 1.1 Scope of the State of Play Report

The principal objective of this report is to identify the current state of climate change adaptation actions that improve the resilience of infrastructure systems in Canada. The focus of the report is on the following themes:

- Water Infrastructure
- Transportation Systems
- Engineered and Non-Engineering Buildings
- Telecommunications

These themes reflect the focus of the IBWG and are not included within the purview of any of the other Adaptation Platform Working Groups. Infrastructure and buildings themes associated with the Agriculture, Coastal Management, Energy, Forestry, Mining and the Northern Working Groups are generally not addressed in this report.

This report emphasizes the impact of adaptation actions on public and community services and the people who depend on them. It identifies gaps and opportunities that exist given the current state of climate change adaptation in Canada.


This report identifies and documents the actions of climate change adaptation innovators and early adopters to establish the current state of adaptation actions in Canadian communities. Particular emphasis is given to the impacts of these adaptation actions on public and community services, and the people who depend on them. Gaps and opportunities that may exist have been identified and recommendations have been made for specific actions to address these gaps. As such, this report will help support the planning, co-operation and co-ordination necessary to engage infrastructure owners, operators, designers, engineers and managers that have not engaged in climate change adaptation. It will provide these stakeholders guidance on improving the resiliency of infrastructure systems.

## 1.2 Background

Infrastructure, whether built, human, or natural, is critically important to people and economies. The purposes of infrastructure are to protect the life, health, property and social welfare of all of its beneficiaries from the weather, to host economic activities, and to sustain aesthetic and cultural values. This report focuses on built infrastructure. In this context, infrastructure includes urban buildings, energy systems, transportation systems (roads, railways or airports), water systems, wastewater and drainage systems, health-care systems, network infrastructure, information and communication systems, and other products of human design and construction. These systems are intended to deliver services to support Canadian's quality of life. In many circumstances, interconnections between various types of infrastructure supports the production and distribution of goods and economic services. Many components of infrastructure, especially those in urban areas, are typically co-located (e.g. power cables laid below roads and beside communications cables, adjacent to water and gas mains and sewers). There are many interdependencies between the infrastructure sectors and failure in one area can quickly lead to a cascading failure of other systems (Robert et al., 2015). For example, the Toronto 2005 extreme rainfall event caused part of Finch Avenue to collapse, severely impacting other systems, including the utilities that ran beneath the road.

About 80% of Canadians live in urban areas (StatsCan, 2011) and rely heavily on built infrastructure. As Public Safety Canada notes, “resilient and secure infrastructure is vital for economic prosperity because it not only underpins the effective operating of businesses and services, but also underpins long term confidence and planning in a region, and thus on-going investment levels” (Public Safety Canada, 2016). When infrastructure[1] fails under extreme weather conditions and can no longer provide services to communities, the result is often a disaster (e.g. the Toronto and Calgary floods in 2013, and drought conditions in parts of Ontario and the Maritimes in 2016). This is especially the case for infrastructure and buildings used by vulnerable populations (e.g. hospitals, homeless and women's shelters, affordable housing, hospices, and long-term care facilities). As the climate changes and extreme weather conditions become more common, it is likely that risks of infrastructure failure will increase. Climate change “… is one of the greatest threats of our time” (Government of Canada, 2016a) and has the potential to impact health, security, and prosperity.


Heat Damage


Wind Damage – Brampton 2016

Since infrastructure is the foundation for so many economic activities, these impacts will be significant and will require adaptation measures. In this context, adaptation refers to “adjustment in natural, human or built systems in response to actual or expected climatic stimuli or their effects that moderates harm or exploits beneficial opportunities” (IPCC, 2001). Even though Canada’s multiple levels of government share responsibilities associated with infrastructure, the effect of climate change is ultimately experienced at the municipal level, even if the problems originate outside of the municipality, such as electrical power disruption. Therefore, municipalities are at the forefront of climate change adaptation activities. Adaptation planning enables government and industry to understand the impacts, risks and opportunities posed by a changing climate and provides a basis for preparation of strategic roadmaps towards long-term resiliency.

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[1] Photo credits previous and current page:
- Finch Avenue Failure, Toronto, August 2005: https://www.thestar.com/content/dam/thestar/news/insight/2012/08/19/climate_change_how_toronto_is_adapting_to_our_scary_new_reality/finchave.jpeg
- Ice Storm 1998: www.nrcan.gc.ca/environment/impacts-adaptation/adaptation-platform/17176#tab-j
- Heat Damage:www.telegraph.co.uk/news/picturegalleries/worldnews/4360255/Heatwave-in-Melbourne-plays-havoc-with-the-Australian-Open.html
- Wind Damage: www.cbc.ca/news/canada/toronto/thunderstorm-toronto-1.3494756

Municipalities are increasingly responsible for infrastructure in Canada. They presently own and maintain about 60% of the country's public infrastructure (FCM et al, 2016). The 2016 Canadian Infrastructure Report Card estimates the total value of municipal infrastructure assets is $1.1 trillion dollars, or about $80,000 per Canadian household with annual investment increasing at a rate of about 1.5% or about $150 billion annually. This level of investment is not keeping pace with the need for maintaining existing infrastructure, let alone accounting for future needs. Canadians are faced with an infrastructure deficit that the Federation of Canadian Municipalities (Mirza, 2007) has estimated to be about $123 billion including:

- Water and Wastewater Systems ($31 billion)
- Transportation ($21.7 billion) and Transit ($22.8 billion)
- Waste management ($7.7 billion)
- Community, Cultural and Social Infrastructure ($40.2 billion)

These figures are growing by $2 billion annually. Other estimates suggest the deficit to be anywhere from $50 billion to $570 billion (Canadian Chamber of Commerce, 2013). The most recent Infrastructure Report Card prepared by the Federation of Canadian Municipalities (2016) indicates the replacement value of assets in *poor* or *very poor* condition to be $141 billion.

The Government of Canada is making efforts to fill this gap through the *Investing in Canada* plan. It has proposed to invest about $120 billion on infrastructure renewal over the next decade with the initial phase of the plan focused on public transit ($3.4 billion over 3 years), water, wastewater and green infrastructure ($5 billion over 5 years) and social infrastructure ($3.4 billion over five years) (Government of Canada, 2016f). Investing in green infrastructure includes the development of building codes and standards that integrate climate resiliency requirements, modernizing water and wastewater infrastructure and seeking out new partnerships on innovative green infrastructure projects and capacity-building programs. Social infrastructure investments will help expand affordable housing (including shelters for victims of violence), support early learning and child care, renew cultural and recreational infrastructure, and improve community health care facilities on reserves (Government of Canada, 2016f). The 2016 Fall Economic Statement proposed an additional $81 billion through to 2027/2028 in public transit, green and social infrastructure, transportation infrastructure that supports trade, and rural and northern communities (Government of Canada, 2016b). Furthermore, in the 2017 Budget, the Government proposes to invest $2 billion for a Disaster Mitigation and Adaptation Fund to support national, provincial and municipal infrastructure required to deal with the effects of a changing climate or the establishment of a new Canadian Center for Climate Services.

Since 1965, the value of building permits issued in Canada totals about $1.7 trillion with over half of the value having been issued since 2000 (StatsCan, 2016c). This total is almost equally split between residential and non-residential permits. Over the period 2011 to 2016, the value of residential building permits has been steadily rising at a rate averaging about 5% annually while the value of non-residential building permits has shown lower growth at an average rate of 2% per year (StatsCan, 2016c).

Infrastructure investment in Canada has enormous value, both as a capital asset and as an essential element contributing to a productive economy. Understanding the value of investments that has been, and will continue to be made for infrastructure and buildings, and risks to that investment from severe weather, reinforces the importance of comprehensive risk assessment taking action to reduce those risks.

Many of these risks are associated with existing vulnerabilities within public infrastructure and building systems. Prevention starts with developing an understanding of the state of existing infrastructure systems and how these systems are connected to the environment and community. Understanding the interplay and dependences of various infrastructure sectors is crucial to preventing the cascading infrastructure failures that have occurred after extreme weather events. Municipalities have already been committed to mitigation initiatives for several years, but cities today can play a larger role by strengthening their capacity to assess vulnerability to climate change impacts and by developing corresponding plans and investments to increase their resilience (Giordano, et al., 2011). There are numerous examples of severe weather events that have had an impact on infrastructure, buildings and communities[2]:

- Burlington Flood, August 2014
  - 3000+ homes flooded / 2 major highways closed
  - $90 million in insured damages
- Calgary Hailstorm, August 2014
  - $450 million in insured damages
- B.C. Summer Heat Wave, 2014
  - Wildfires burn 360,000 hectares of land
  - 4,500+ people forced to evacuate
- Manitoba Flood, June 2014
  - $1 billion in insured damages
- Toronto Flood, July 2013
  - $999.5 million in insured losses (IBC, 2016) 300,000 residents lost power
  - 1,400 passengers stranded on a commuter train
  - 1 subway station flooded
- Calgary Flood, June 2013
  - $3 to $5 billion in damages
  - 120,000 people forced out of their homes
  - 10 years to rebuild communities
  - 1,200 Siksika First Nation residents evacuated
- Calgary-area Wind / Hail Storm, August 2012
  - $535 million in insured damages
- Quebec and Atlantic Canada, Tropical Storm Irene, August 2011
  - $140 million in insured damages
- St-Jean-sur-le-Richelier Flood, April 2011
  - 3000 disaster victims
  - $52 million in compensation
  - 800 soldiers mobilized
  - More than 100 houses destroyed
- Fort McMurray Fire, May-June 2016
  - Canada's costliest catastrophic event
  - $3.6 billion in insurance damages[3]

Data on insured losses does not typically represent the total economic impact of disasters, as not all infrastructure is insured. There are also broader social losses related to uninsured property and infrastructure, emergency response and intangible costs such as death, injury, and relocation,

[2] Sources: CBC News, 2014; Global News, 2016; Public Safety Canada, n.d., City of Burlington, n.d., IBC Fact Book, 2016, TD Economics, 2014
[3] Sources: Geoffrey Morgan, 2016; CatIQ, 2017

which are borne by many parties including individuals, communities, businesses, governments, and insurers.

In 2016, the Intact Centre on Climate Adaptation completed a study called *Climate Change and the Preparedness of Canadian Provinces and Yukon to Limit Provincial Flood Damage*. The study assessed flood preparedness relative to current (2016) and future (2030) major precipitation events and provides direction to the provinces and territory to build efforts to limit flood risk. The state of provincial and territorial flood preparedness was based on a survey of 103 government representatives across 91 provincial and territorial ministries. It examined floodplain mapping, land-use planning, drainage maintenance, sustainable flood management, home and commercial property adaptation audits, transportation systems, electricity supply, drinking water systems, wastewater systems, public health and safety and emergency preparedness and response. Based on the survey, the average Canadian flood preparedness score, across all the provinces and Yukon, is C-. This score suggests that Canada needs to improve by a considerable margin to better prepare for, and potentially mitigate, future flood risk. The report noted that the risks of the past are not the risks of the present, and certainly not the risks of the future. It should be a priority to establish Chief Adaptation Officers in provinces and territories for governments to address the growing extreme weather challenges (Feltmate, 2016).

In 2008 it was written that “The question today is not whether adaptation will occur but when and how it will occur. Some adaptation will occur spontaneously. […] In other cases, adaptation requires effective planning, co-operation and co-ordination. A proactive approach is likely to improve success of adaptation initiatives and reduce the associated costs” (Burton, 2008).

It is important to consider that making adaptation a normal course of action in day-to-day operations requires a systemic administrative approach rather than one that can be fixed solely by technology. Systemic barriers include limited knowledge and awareness, insufficient data and tools to assess risks, fragmented governance, lack of political commitment, and market pressures. Although these issues may not directly influence adaptation decision-making, they can negatively impact legislative frameworks and industry accepted approaches and methods (Filho, 2016, Amec Foster Wheeler, 2016). Notwithstanding these barriers, there have been some sporadic actions from innovators in the past number of years and the early adopters are currently being engaged. These individuals, however, only represent a small portion of the overall group that needs to be engaged (MaRS, 2009).

## 1.3 Natural Resources Canada Adaptation Platform

The Natural Resources Canada Adaptation Platform (the “Platform”) brings together key groups from government, industry, and professional organizations to collaborate on adaptation priorities as a framework to pool knowledge, capacity, and financial resources. The Climate Change Impacts and Adaptation Division (CCIAD) at Natural Resources Canada (NRCan) leads the Platform. The Platform structure includes a Plenary (the coordinating forum) and thirteen (13) Working Groups. It promotes collaboration among those who have a collective stake and role to play in making Canada more climate-resilient.

### 1.3.1 Overview of the Adaptation Platform Working Groups

The Adaptation Platform Working Groups of Natural Resources Canada bring together people with expertise and/or common interest in specific issues or sectors. Members collaborate to define objectives, and then work towards achieving them. Members may contribute to this work by providing funding, expertise and information from their organizations, writing and reviewing documents, acting as advisory committee members on projects, hosting meetings, etc. Members come from public and private sectors, academia and professional associations, and are nominated by plenary members. The Adaptation Platform Working Groups are:

- Agriculture
- Coastal Management
- Economics
- Energy
- Forestry
- Infrastructure and Buildings
- Measuring Progress
- Mining
- Northern
- Regional Adaptation Collaboratives (RAC) and Tools Synthesis
- Science Assessment
- Water and Climate Information
- Enhancing Uptake and Use of Resources

### 1.3.2 Overview of the Infrastructure and Buildings Working Group

The Infrastructure and Buildings Working Group (IBWG) was established by the Institute for Catastrophic Loss Reduction (ICLR) and Engineers Canada, in consultation with Natural Resources Canada, in 2013. The IBWG's purpose is to build capacity, collect evidence and provide outreach to increase the capability of infrastructure managers, municipalities, builders, insurers, engineers and other relevant stakeholders to adapt and facilitate adaptation to climate change. The IBWG is comprised of climate change adaptation stakeholders from federal and provincial governments, private industry and non-profit organizations from across Canada.

To date, the IBWG has developed projects that focus on:

- Development of climate change data and information to support the consideration of climate resilience infrastructure planning, design, operations and maintenance decisions
- Assessments of the climate vulnerability of civil infrastructure and systems as well as various types of buildings using the Engineers Canada, Public Infrastructure Engineering Vulnerability Committee Protocol in over forty (40) projects in Canada
- Identification and dissemination of municipal best practices for managing extreme rainfall risk
- Development of methods and strategies for incorporating disaster resilience into new and existing low-rise residential structures
- Facilitation of immediate post-disaster social-science research
- Development of construction code submissions to improve climate change resilience in new low-rise residential structures
- Identification of best practices that can be incorporated into new subdivisions to reduce extreme rainfall flood risk
- Development of legal tools to support property-level urban flood mitigation

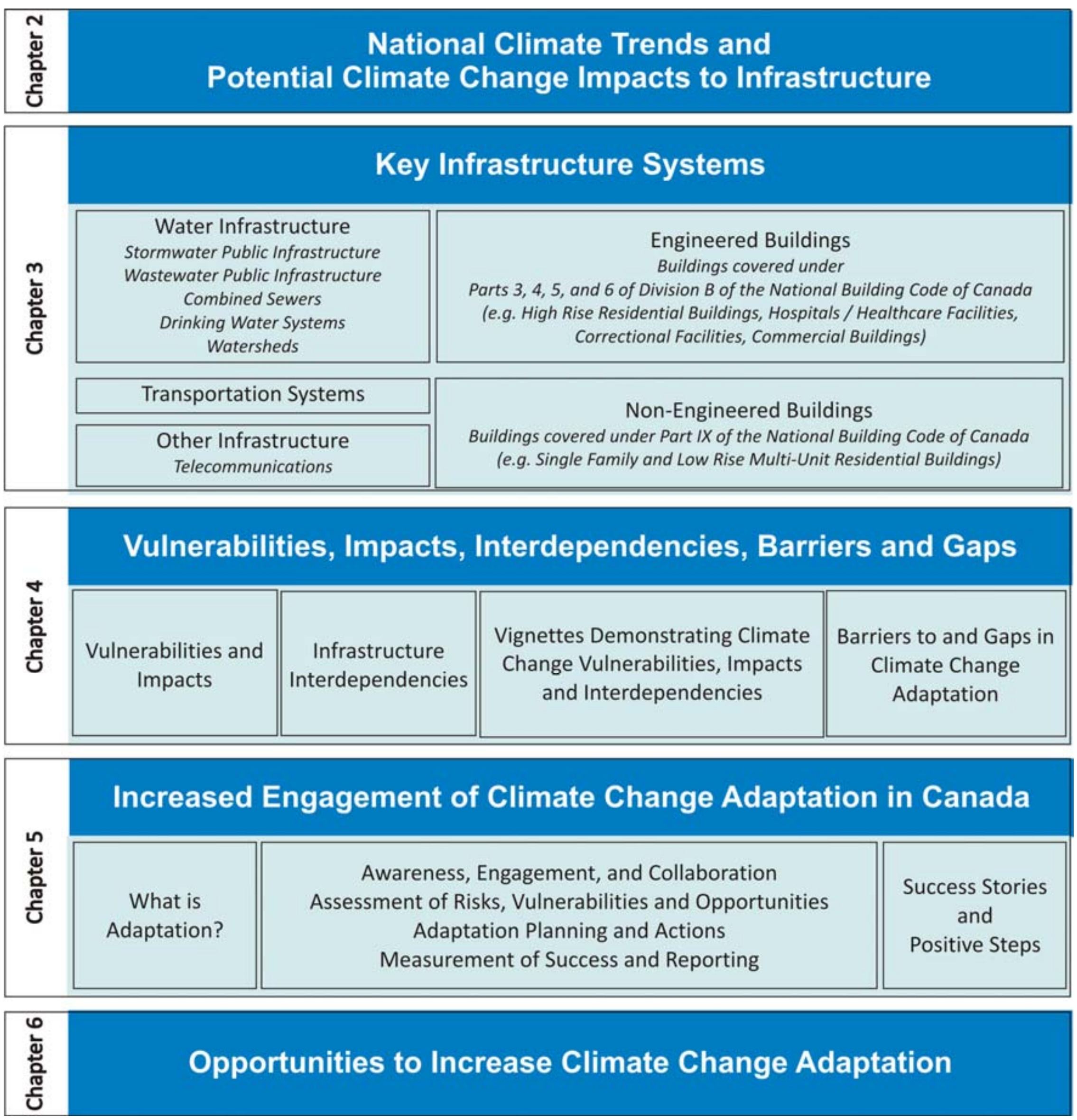
- Improvement of the understanding of flood mitigation technologies applied at the private property-scale to reduce extreme rainfall flood risk

## 1.4 Document Structure

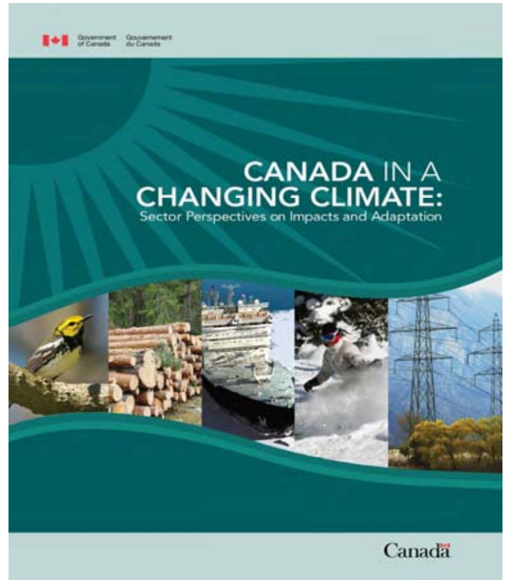
This State of Play report has been structured (ref. Figure 1-1) in a manner that focuses on:

- Key infrastructure and buildings themes
- Possible climate change impacts and risks
- The development of climate change adaptation in Canada and present status
- Opportunities to remove barriers or give rise to new or advance existing initiatives

**Figure 1-1 State of Play Report Structure**



# 2.0 National Climate Trends




A vast collection of literature and data is available about weather and climate in Canada. *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (Warren and Lemmen, 2014)[4] provides a synopsis of past climate trends and anticipated changes which are expected under a changing climate for all areas of Canada.

More regionally specific information regarding climate trends and future climate projections are available as components of a series of climate change vulnerability assessments completed using the PIEVC Engineering Protocol[5]. Each PIEVC report will have some climatic evaluations as part of the specific overall assessment. About forty (40) such assessments have been completed to date with examples from all regions of Canada for a broad variety of public infrastructure including water supply systems, stormwater collection and management systems, wastewater treatment facilities, transportation (road, rail and airport) systems, etc.

## 2.1 Potential Climate Change Impacts to Infrastructure

The theme of infrastructure and buildings, in the context of this State of Play report, embodies a wide array of structures, systems, components, etc. The design of infrastructure and buildings are guided by numerous codes and standards, some of which reflect a changing climate, some that have yet to, and some that will not need to. It is not difficult to understand that different types of infrastructure have the potential to be impacted by climate phenomena. The summaries presented in Tables 2-1 and 2-2 have been abstracted from Warren and Lemmen, 2014.

Additional information on this topic is provided in Section 4.0 of this report.

[4] Available at URL: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf
[5] Available at URL: https://pievc.ca/

## Table 2-1 Examples of Observed Climate Changes in Canada

**(Source: Warren and Lemmen, 2014, Warner et al, 2015)**

| Climate System Element | Observed Historic Trends |
|---|---|
| Temperature | |
| Annual air temperature | The annual average surface air temperature over the Canadian landmass has warmed by 1.5°C over the period 1950-2010 |
| Hot extremes | The frequency of warm days (when the daily maximum temperature is above the daily 90th percentile) during the summer has increased across Canada since 1950 |
| Cold extremes | The frequency of cold nights (when the daily minimum temperature is below the daily 10th percentile) during the winter has decreased across Canada since 1950 |
| Precipitation and other hydrological indicators | |
| Annual precipitation | Canada has generally become wetter in recent decades, as indicated by the increasing trend in annual average precipitation |
| Snowfall/Rainfall | In several regions of southern Canada, there has been a shift in precipitation type, with decreasing snowfall and increasing rainfall |
| Streamflow | Observations suggest decreasing trends in maximum and minimum river flows over the period 1970-2005 in much of southern Canada, with increases in minimum flows in western Nunavut, Northwest Territories, Yukon and northern British Columbia |
| Snowfall | Annual snowfall has declined over southern Canada / increased in the north over the last 6 decades |
| Snow cover | Decreasing trends in snow cover extent have been observed during spring over the Canadian landmass, with largest declines observed in June |
| Rising groundwater table | Rising groundwater levels observed in cities throughout parts of North America demonstrate that proactive management of urban groundwater is required whether or not it is used for potable supply |
| Permafrost | |
| Ground temperature | Permafrost temperatures at numerous borehole sites across Canada have increased over the past two to three decades |
| Sea Level | |
| Sea level | Global average sea level rose about 21 cm between 1880 and 2012; average rate of 1.6 mm/year |
| Relative sea level | Relative sea level rise of over 3 mm/year has been observed on coastlines of Atlantic Canada and the Beaufort Sea coast, with lower amounts along Pacific coastlines. Relative sea level fall of 10 mm/year has been observed around Hudson Bay where the land is rising more rapidly than the sea level due to post-glacial rebound. |
| Sea Ice | |
| Seasonal ice extent | End-of-summer minimum Arctic ice extent has declined at a rate of 13% per decade over 1979-2012, while maximum winter sea ice extent has declined at a rate of 2.6% per decade. Declines in winter sea ice extent have been observed in the Labrador-Newfoundland and Gulf of St. Lawrence regions |
| Ice type | A shift in Arctic ice cover composition from one dominated by thick multi-year ice to one increasingly dominated by thin first-year ice has been observed |
| Glaciers | |
| Glacier mass | Western Cordilleran glaciers are losing mass and shrinking rapidly to the smallest extents in several millennia. Glaciers in British Columbia and Alberta have lost, respectively, about 11% and 25% of their surface area over the period 1985-2005. Glaciers in Yukon have lost about 22% since the 50's |
| Glacier mass | Significant mass losses are evident from the early 1960s into the first decade of the 21st century. The rate of mass loss for glaciers throughout the High Arctic has increased sharply since 2005, in direct response to warm regional summer temperatures |
| Lake and River Ice | |
| Spring ice thaw | Trends towards earlier ice-free dates (lakes) and ice break-up dates (rivers) have been observed for most of Canada since the mid-20th century but are particularly evident in Western Canada |
| Ocean Climate | |
| Canada's oceans | Long-term changes in ocean temperature (increasing), salinity (variable sign), and acidity (increasing) have been observed in all three of Canada's oceans. Long-term decreases in subsurface dissolved oxygen levels have also been observed in the Atlantic and Pacific oceans off Canada |

## Table 2-2 Examples of Projected Changes Canada's Climate System

**(Source: Warren and Lemmen, 2014)**

| Climate Phenomena | Projected Changes |
|---|---|
| Temperature | |
| Seasonal temperature | Warming will be greatest in winter, and in this season, the largest increases in air temperature are projected for northern Canada. In summer, the largest increases are projected for southern Canada and the central interior. The magnitude of projected warming varies substantially with the emission scenario |
| Extremes in daily temperature | Increases in the frequency and magnitude of unusually warm days and nights and decreases for unusually cold days and nights are projected to occur throughout the 21st century |
| Long duration hot events | The length, frequency and/or intensity of warm spells, including heat waves, are projected to increase over most land areas, including Canada |
| Rare hot extremes | Rare hot extremes are currently projected to become more frequent. For example, a one-in-20-year extreme hot day is projected to become about a one-in-5 year event over most of Canada by mid-century |
| Precipitation and other hydrological indicators | |
| Seasonal precipitation | Increases in precipitation are projected for the majority of the country and for all seasons, with the exception of parts of southern Canada where a decline in precipitation in summer and fall is suggested |
| Heavy precipitation | More frequent heavy precipitation events are projected, with an associated increased risk of flooding |
| Rare precipitation events | Rare extreme precipitation events are currently projected to become about twice as frequent by mid-century over most of Canada |
| Streamflow | Increases in winter streamflow are projected for many regions in southern Canada. Mean annual streamflow is projected to decreases in some regions of Alberta and Saskatchewan, while projections for other regions vary across different scenarios |
| Snow Cover | |
| Snow cover duration | Widespread decreases in the duration of snow cover are projected across the Northern Hemisphere with the largest changes in maritime mountain regions, such as the west coast of North America |
| Snow depth | Maximum snow accumulation over northern high latitudes is projected to increase in response to projected increases in cold season precipitation[6] |
| Permafrost | |
| Ground temperature | Warming of the permafrost is projected to continue at rates surpassing those observed in records to date. Low average temperatures of much of the permafrost in the Arctic mean it will take many decades to centuries for colder permafrost to completely thaw |
| Sea Level | |
| Global sea level rise to 2100 | Estimates of the magnitude of future changes in global sea level by the year 2100 range from a few tens of centimetres to more than a metre |
| Global sea level rise beyond 2100 | Projections of global sea-level rise beyond 2100 indicate continuing global sea-level rise over the coming centuries and millennia. Global sea-level rise may eventually amount to several metres |
| Relative sea level change | Patterns of change along Canadian coastlines will continue to be influenced by land uplift and subsidence as well as by changes in the oceans. Sea-level rise will continue to be enhanced in regions where the land is subsiding, and sea level is likely to continue to fall in regions where the land is rapidly rising. Regions where the land is slowly rising may experience a transition from sea level fall to sea level rise. |
| Ice | |
| Arctic summer sea ice | A nearly ice-free summer is considered a strong possibility for the Arctic Ocean by the middle of the century although summer sea ice may persist longer in the Canadian Arctic Archipelago region |
| Lake Ice | With the continued advance of ice cover break-up dates and delays in ice-cover freeze up, ice cover duration is expected to decrease by up to a month by mid-century |

[6] The comment stems from analysis of the CMIP3 ensemble. Review of the newer CMIP5 ensemble suggests that this increase will be temporary as under RCP 8.5 at time horizon 2080 the warming trend is so strong that the increase in precipitation no longer contributes to the increase of the snow depth (at least in Northern Québec). Reference https://www.ouranos.ca/publication-scientifique/SyntheseRapportfinal.pdf

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# 3.0 Key Infrastructure Systems

This section provides an overview of the key infrastructure systems addressed in this report with an emphasis on infrastructure that is not under the mandate of other Adaptation Platform Working Groups (ref. Section 1.1) and on both engineered and non-engineered buildings with a focus on the following themes:

- Water Infrastructure
  - *Stormwater Infrastructure*
  - *Wastewater Infrastructure*
  - *Drinking Water Systems*
  - *Watersheds*
- Transportation Systems
- Engineered Buildings
  - *Multi-Unit Residential*
  - *Hospitals / Healthcare Facilities*
  - *Correctional Facilities*
- Non-Engineered Buildings (as defined in Part IX of the National Building Code of Canada)
- Other Infrastructure
  - *Telecommunications*

## 3.1 Infrastructure Lifecycle Timeframes

Climate change is influencing the costs and timelines for the infrastructure lifecycle covering planning, design/construction, operations, maintenance (including routine repair, major rehabilitation/retrofits/additions/alterations), decommissioning/demolition and transformation (i.e. change of use) (CSA, 2006). Infrastructure planners and designers are turning a critical eye to design criteria, design performance levels and evaluation of the potential impacts of climate change on future capital expenditures. Understanding these influences contributes to better, more informed decision-making and policy development by providing a basis for establishing priorities. Table 3-1 summarizes the typical design lifecycle activities for the various types of infrastructure which are the focus of this report. Planning decisions should be made in the near future for both existing and new infrastructure in these sectors, as there is a very high probability of direct impacts to these systems as a result of the changing climate (Environment Canada, 2004).

**Table 3-1 Infrastructure Lifecycle Timeframes**

(Sources: Environment Canada, 2004; Bélanger, 2013; Nevada Department of Taxation, 2015, FCM et al, 2016)

| Infrastructure | Type / Action / Phase | Typical Lifecycle / Useful Life (Years) |
|---|---|---|
| Stormwater Management | Sewers | 80-100 |
| | Catch basins and leads | 60-100 |
| | Culverts | 25-35 |
| | Treatment Facilities | 30-50 |
| Wastewater Systems | Major refurbishment | 20-30 |
| | Interceptor and trunk sewers | 120-150 |
| | Sewers (<450 mm) | 100-120 |
| | Manholes | 75-100 |
| | Pumping Stations: Short-life / Long life | 15-30 / 50-75 |
| Drinking Water Systems | Major refurbishment | 20-30 |
| | Reconstruction/Major Upgrade | 50 |
| | Mains to plant, Hydrants | 75-100 |
| | Pumping Stations: Short-life / Long life | 10-35 / 50-100 |
| Roads | Maintenance | Yearly |
| | Resurface | 5-10 |
| | Reconstruction/Major Upgrade | 20-50 |
| | Expressway | 15-18 |
| | Urban Arterial – Major / Minor | 15-18 / 25-40 |
| | Urban local / Rural local | 30-35 / 40-50 |
| | Curbs and sidewalks | 40-50 |
| Bridges | Maintenance | Yearly |
| | Resurface concrete | 20-25 |
| | Reconstruction / Major Upgrade | 60-100 |
| Rail | Major refurbishment | 10-20 |
| | Reconstruction/Major Upgrade | 50-100 |
| Commercial Buildings | Retrofit<br>Demolition | 25-50<br>50-100 |
| Residential Housing | Additions/Renovations<br>Demolition | 15-20<br>60-100 |
| Telecommunications | Reconstruction/Major Upgrade | 20-60 |

## 3.2 Water Infrastructure

For the purpose of this Report, water infrastructure has been defined to include the traditional man-made or built infrastructure components (stormwater, wastewater, combined sewers drinking water) and the natural infrastructure (rivers, lakes, streams, groundwater aquifers, floodplains, floodways, wetlands), and the watersheds that serve or are affected by water, stormwater and wastewater systems.

### 3.2.1 Stormwater Public Infrastructure

Stormwater management has been in the public eye given the flooding in Alberta and the Greater Toronto Area (GTA) in recent years. Stormwater refers to water that runs off the land and ultimately makes its way towards receivers including wetlands, watercourses (i.e. rivers, streams, etc.) and lakes. In an urban context, stormwater management strategies may vary from managing rain where it falls through lot level controls typically designed to infiltrate rain, (i.e. green roofs, permeable pavement) to conveyance systems designed to move runoff away from urban areas into “end of pipe” systems such as detention ponds. These ponds (wet and dry) are designed to reduce riverine flooding, erosion and remove pollutants before entering the receiving waterway.

The timeline of urbanization is significant for stormwater infrastructure systems as the age of development provides a general sense of the age of infrastructure. It also provides a sense of the level of stormwater service. Unlike municipal wastewater and drinking water collection systems which deliver a consistent level of service across a municipality regardless of the age, this is generally not the case for stormwater. Stormwater management has evolved over the past 40 years and as a result, there are typically varying levels of service within a municipality. In general, for developments built prior to the early 1980s, stormwater (or flood control) was not a requirement and roads were not designed to convey excess runoff away from development. In the early 1980s, stormwater management began to focus on controlling the quantity of runoff

[7] Photo credit: http://www.thebluebook.com/inc/img/qp/2025169/catch-basin-grate.jpg

through use of ponds. Roof runoff from residential downspouts was commonly connected to public sanitary and/or combined sewer systems, exacerbating sanitary inflow/infiltration issues, and increasing risk of flooding and CSOs. By the early 1990s, practitioners put additional focus on water quality and downstream erosion control using permanent wet ponds. Today across Canada, in the absence of national standards, there are two types of conveyance systems. Major systems which are overland systems (typically roadways) used to convey large storm events away from the urban area. Minor systems, such as underground storm sewers, are designed for smaller events. The conventional stormwater practice for designing stormwater conveyance systems is to use Intensity-Duration-Frequency (IDF) relationships, for different return period storms, based on historical data. Since the 1970s, minor and major systems have been typically designed to convey the 1:10 year and 1:100 year storm, respectively, while roadway watercourse crossings are sized for between the 25-year and 100-year return period storm, depending on the classification of the roadway. Water quality and runoff volume control standards vary across the provinces and territories.

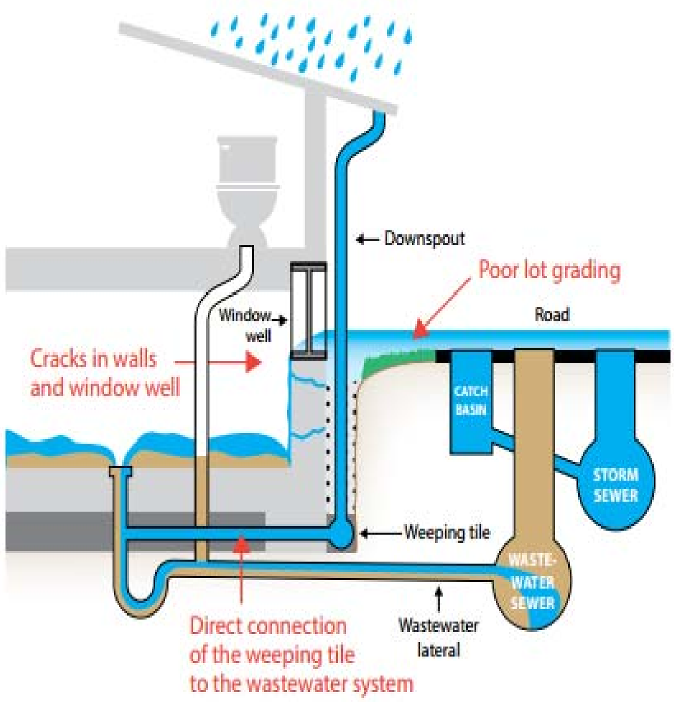
With improvements in watershed management and a growing ability to understand watersheds themselves, stormwater management is beginning to shift from management of peak flows towards controlling runoff volume. The goal is to mimic the natural water balance to maintain groundwater recharge, dry weather streamflows to help protect recreational uses and ecological systems. There is increased focus on treating stormwater in a treatment train approach, similar in concept to water and wastewater treatment processes. Stormwater is treated at the source, through conveyance, and at end of pipe systems prior to discharge into a receiving water body. Some examples of municipal programs designed to achieve these goals includes implementing downspout disconnects and rain garden stewardship programs. The goal is to improve residential source control in an attempt to reduce basement flooding, improve runoff water quality, and increase water conservation.

When a stormwater system is overwhelmed, two types of flooding may occur: *urban* and *riverine* flooding (ref. Figure 3-1). *Urban flooding* is caused by excessive rainfall events that overwhelm the storm and/or sanitary sewer system causing inundation of properties. There are two types of *urban flooding*: *overland* and *basement* flooding. *Overland flooding* of buildings occurs when stormwater enters through above ground openings, including windows, doorways, unsealed utility penetrations, cracks in foundation walls, etc. as well as below-grade entranceways, including exterior, below-grade basement access doors and reverse slope driveways. Overland flow may also percolate into backfill areas surrounding foundations and infiltrate through foundation walls and basement floors. Overland flooding is often due to ponding from poor lot grading. *Basement flooding* occurs due to overland flooding, infiltration flooding and/or sewer backup. Infiltration flooding plays a key role in basement flooding where soils around the property become saturated due to steady rain, spring snowmelt or extreme rainfall event. *Riverine flooding* is caused by extreme events such as excessive rainfall, hurricanes, rainfall and snowmelt events or ice jams. Such extreme events cause the river water levels to rise and spill into the floodplain zone. Extreme events of short duration and high intensity can result in a larger floodplain with more structures in the floodplain as opposed to the design storm limits. The location of new development areas can also exacerbate urban and riverine flooding when these areas (or redevelopment, infill development) are up gradient of older areas without the appropriate capacity to accommodate additional stormwater flows.

The estimated replacement value of stormwater collection and management systems is $40.8 billion across Canada (CCA et al, 2012). This value does not take into consideration the need for new infrastructure to service areas not yet receiving stormwater control to current standards. Roughly 35 per cent of the GTA had stormwater management controls as of 2013 (TRCA, 2013). An additional $56.6 billion is needed to address new stormwater infrastructure needs nation-wide (FCM, 2007). Land costs to install grey infrastructure within existing urban areas can be as high as three or four times that of infrastructure within Ontario's Greater Golden Horseshoe (Colliers International, 2016). It is uncertain, given the vulnerabilities identified after the extreme events in 2013, that current standards will provide the level of protection needed to safeguard communities.

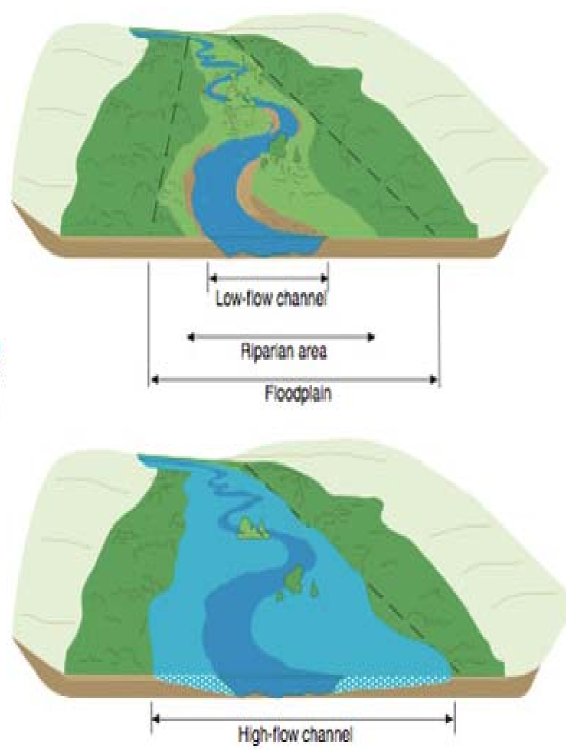
Refer to Appendix A for further information on stormwater systems and current national standards for stormwater management.

**Figure 3-1 Overview of Riverine and Urban Flooding**




**Urban Flooding**

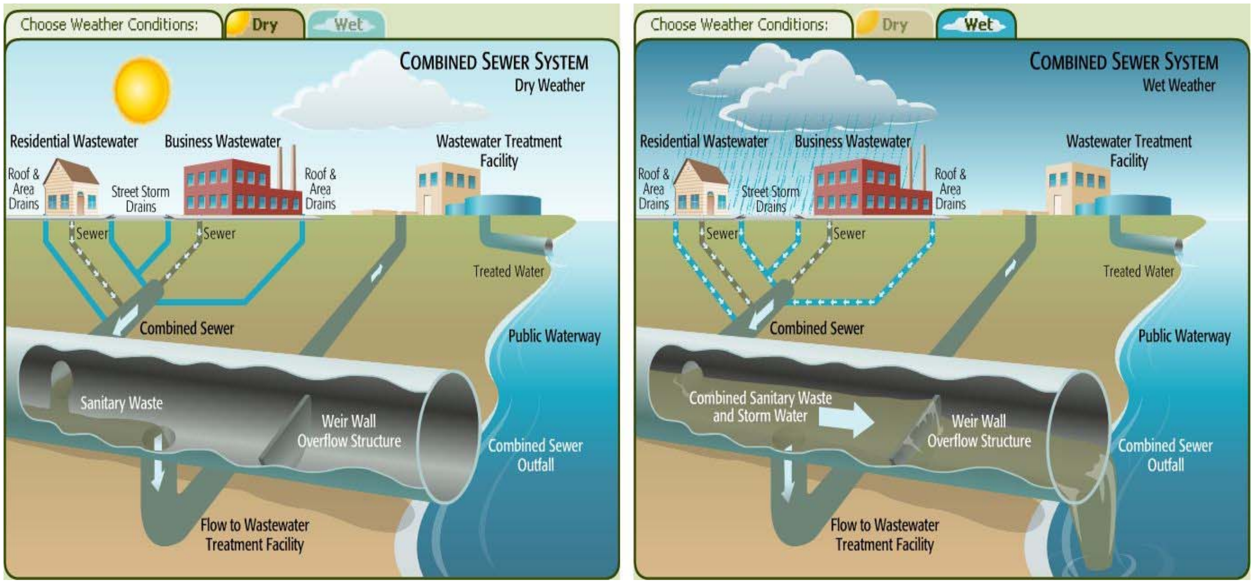
**Source: Halton Region, 2016**




**Riverine Flooding**

**Source: AWSMP, 2016**

### 3.2.2 Combined Sewer Systems




Combined sewer systems are designed to collect stormwater runoff and wastewater in the same pipe. Most of the time, these systems transport all of their combined effluent to a municipal wastewater treatment plant, where it is treated and then discharged to a receiving water body. However, heavy rainfall or snowmelt events may exceed the capacity of the combined sewer system or treatment plant causing the system to discharge excess effluent directly to the receiving water body. These overflows, called combined sewer overflows (CSOs), contain both untreated stormwater and wastewater.

Most urban areas built prior to the early 1940s are typically served by combined sewers (Chambers, et al., 1997). In Ontario, at least 89 municipalities have combined sewers (Ecojustice, 2010). Lost revenue from beach closures along the greater Toronto shoreline, which often result from CSOs, is estimated at $776 million to $1.5 billion/year (Marbek, 2010). In Greater Vancouver, British Columbia, it is estimated that 53 CSOs discharge to the lower Fraser River and estuary (Chambers et al, 1997).

While not considered combined sewers, municipalities with separate sewer systems may also have cross-connections between their stormwater and wastewater sewers. Inflow and infiltration of stormwater into sanitary sewers also impacts their capacity. This can play a large factor during storm events, if stormwater flows overwhelm wastewater sewer systems and lead to back-ups, basement flooding, and bypass of sewage treatment.

[8] Image Credit: http://wordpress.storage.hkywater.org/wp-content/uploads/2014/06/CSO-Animation-Combined-Link.jpg

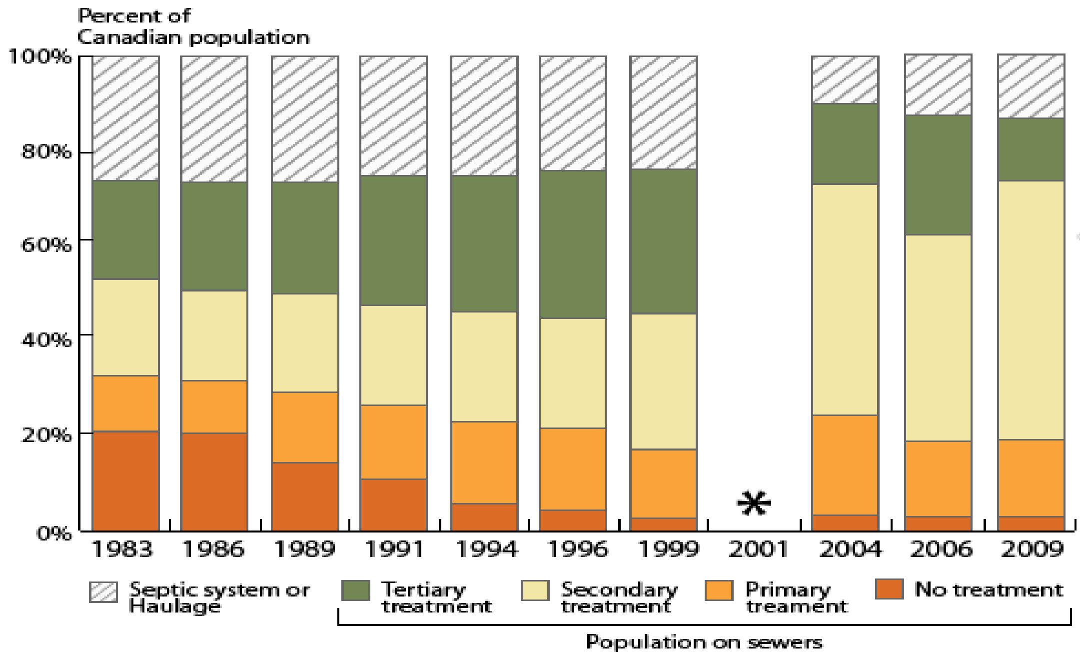
### 3.2.3 Wastewater Public Infrastructure


This State of Play report has focused on municipally owned wastewater treatment systems. Municipal wastewater systems collect, convey and treat raw sewage from homes, institutions and businesses before releasing treated effluent to the environment. Wastewater collection and treatment systems typically include sanitary sewer mains, sewage pumping stations, and wastewater treatment facilities or communal wastewater treatment plants. Treated effluent from these facilities discharges to receiving water bodies such as lakes or rivers.

The sanitary sewer network (collection and transmission systems) collects wastewater from homes, institutions and businesses. The level of wastewater treatment provided by a municipality will vary depending on general provincial or territorial requirements and requirements specific to the receiving water body. Most municipally owned wastewater treatment facilities will provide primary and secondary treatment. In general, where water supply is scare, wastewater reuse has become a necessity, requiring a tertiary level of treatment. A by-product of wastewater treatment is bio-solids (pollutants removed from wastewater through screening, settling or biological/physical or chemical processes). Bio-solids may be reused, burned, buried, or disposed of depending on the provincial regulations and bio-solids composition.

Figure 3-2 below illustrates the percentage of the Canadian population with different levels of municipal wastewater treatment between 1983 and 2009. The percentage of Canadians on municipal sewers with secondary treatment or better has improved from 40% in 1983 to 69% in 2009, leaving approximately 18% with primary treatment or less and another 13% of Canadians using household septic systems to treat their sewage (ECCC, 2016b).

[9] Photo Credit: http://um-images.s3.amazonaws.com/2009/07/treatmentplant_aerial.jpg (Montreal Wastewater Treatment Plant)




*The bar chart illustrates the percentage of the Canadian population with different levels of municipal wastewater treatment between 1983 and 2009. No data is available for 2001 as there were not enough respondents to produce meaningful results.*

**Figure 3-2 Different Levels of Municipal Wastewater Treatment**

(Source: ECCC, 2016b)

Occurrences of raw sewage flushing are among the highest in Newfoundland and Labrador, Nova Scotia, Manitoba, and British Columbia and this has increased their contribution of untreated wastewater into rivers and the ocean between the periods of 2013-2015 (Thompson, 2016; ref. Figure to right). Alberta, Saskatchewan, Ontario and New Brunswick are introducing additional levels of treatment. The problem of raw sewage entering the rivers and oceans will only exacerbate with climate change causing more heavy rainfall events.

Refer to Appendix A for further information on wastewater systems and current national standards for wastewater management.

**Percentage of waste water that goes untreated across Canada** (by province)

LOW — HIGH

| | 2013 | 2014 | 2015 |
|---|---|---|---|
| British Columbia | 10.0% | 12.4% | 12.7% |
| Alberta | 1.9% | 1.5% | 1.0% |
| Saskatchewan | 0.0% | 0.02% | 0.0% |
| Manitoba | 5.6% | 6.1% | 8.4% |
| Ontario | 1.2% | 1% | 0.9% |
| Quebec | na* | 1% | 1.3% |
| New Brunswick | 17.7% | 13.8% | 12.9% |
| Nova Scotia | 20.8% | 9.4% | 24.0% |
| Prince Edward Island | 7.7% | 10.3% | 5.1% |
| Newfoundland and Labrador | 13.4% | 7.2% | 16.6% |
| Canada overall | 4.2* | 3.4% | 3.9% |

* 2013 total excludes Quebec/no data available

Source: Thompson, 2016

### 3.2.4 Drinking Water Systems

For this State of Play report, only municipal drinking water systems have been assessed. Municipal drinking water refers to water consumed by residents, institutions and businesses that is provided by the local municipality. Municipal drinking water systems commonly include both surface-based (lake or river) and groundwater-based sources. Municipal water distribution systems typically include transmission mains that bring water from treatment facilities to storage facilities and between pressure zones, as well as feeder mains that exist on most streets and service connections to bring water into buildings.

**Photo 3-1 An algae clogged intake basket from a surface water treatment plant**

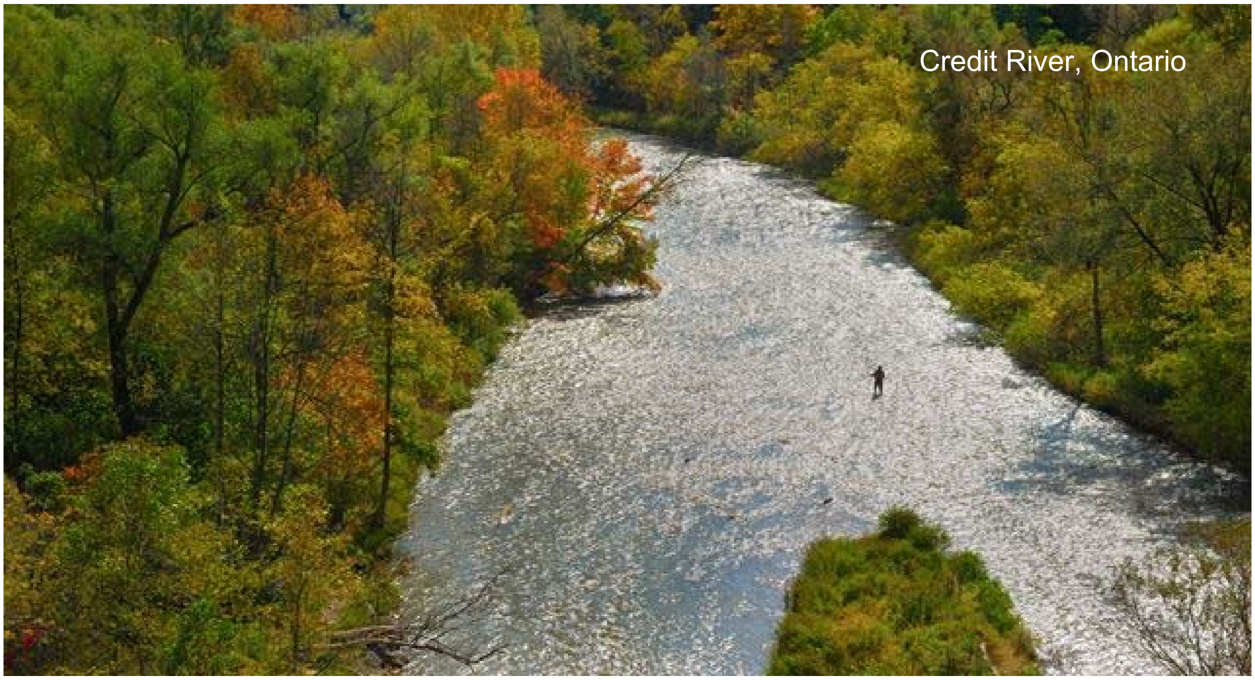
*Algae growth in the water plant caused temporarily shut down for 6 hours for cleaning at a cost of $350,000. When shutting a water plant down, there is risk of being unable to maintain pressure to avoid recontamination in the distribution pipes. With warmer winters and hotter summers, algae is becoming an increasing concern and the need to address nutrient removal in wastewater and stormwater apparent*.

The treatment processes required to meet regulations for Canadian Drinking Water Quality and the standards technical documents depend largely on the quality of the source be it groundwater or surface water. The Standards for Canadian Drinking Water Quality deal with microbiological, chemical and radiological contaminants and address concerns with physical characteristics of water, such as taste and odour.

Refer to Appendix A for further information on drinking water systems and current national standards for drinking water quality across Canada.

[10] Photo Credit: http://oeconline.org/wp-content/uploads/2014/11/Dollarphotoclub_57954146.jpg

### 3.2.5 Watersheds




There is growing awareness that traditional age and condition assessments are not sufficient to determine performance levels for water, wastewater and stormwater infrastructure. When assessing the state of municipal water, wastewater and stormwater infrastructure, it is necessary to consider these systems in a watershed context. Going beyond the municipal boundaries can help to understand water-related vulnerabilities and interconnections that may exist.

An integrated watershed approach is needed to set a level of service to optimize stormwater, water and wastewater operations. Figure 3-3 illustrates a conceptual watershed that highlights the linkages between land-use management, water, wastewater, stormwater and the environment. For example, land management decisions upstream can have downstream implications such as reduced dry weather streamflow. This can impact the assimilation of wastewater effluent limiting growth downstream or requiring more costly wastewater treatment to meet more stringent wastewater requirements due to lower streamflows).

Similarly, stormwater management decisions could impact groundwater recharge, which could affect municipal drinking water supply and quality. These interconnections between water systems only become apparent when viewed from a watershed perspective.

Communities reliant on groundwater for drinking water supply are particularly vulnerable during drought conditions. An Integrated Watershed Management Study (CVC et al, 2014) found that urbanization would increase the amount of permeable surfaces (reducing groundwater recharge) while increasing water takings. This would decrease streamflow which would in-turn impact the dilution of wastewater treatment plant (WWTP) effluent in the stream. This would negatively

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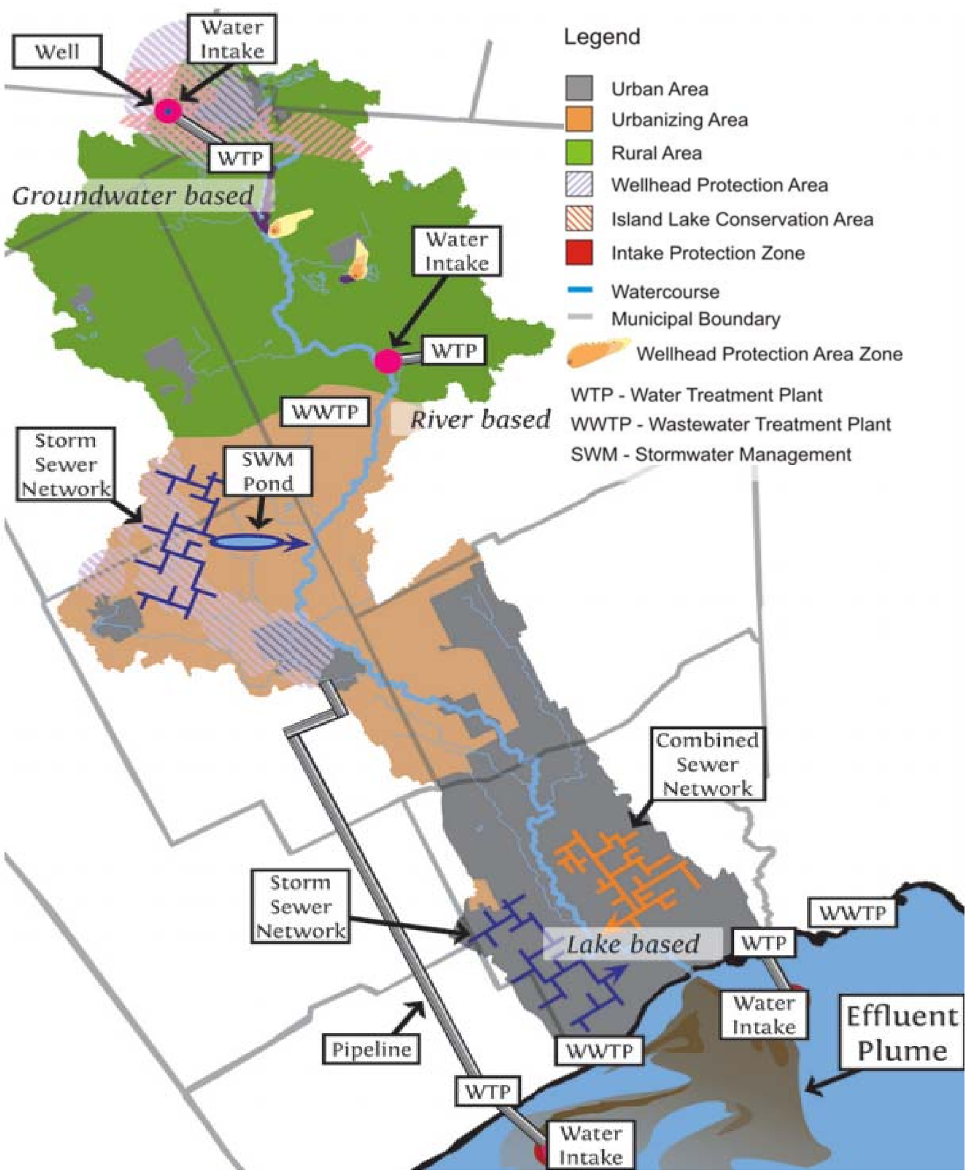
[11] Photo Credit:
http://media.zuza.com/2/c/2cd49b85-26ab-445c-8684-11b848b0c916/File-NX-M-Greenbelt___Gallery.jpg

impact fisheries and impact the assimilative capacity of municipalities downstream. The study found that $25.5 million in WWTP upgrades are needed to enhance treatment levels while compensating for lower streamflows. Alternatively, the study found that if stormwater retrofits were implemented within existing urban areas with green infrastructure (GI), the groundwater and streamflows would be maintained requiring no WWTP upgrades. The cost for this option was only $15.5 million (CVC et al, 2014). The stormwater retrofit options also offered additional benefits such as reduced flooding, erosion and improved water quality to the receiving stream. This study demonstrates the cost-benefit of integrating water, wastewater and stormwater investment on a watershed basis.

**Figure 3-3 Example Graphic to Illustrate Watershed Interconnectivity**

(Map source: CVC et al, 2014)



## 3.3 Transportation Systems


Transportation services account for 4.2% of the Canadian GDP with the Canadian transportation system having an asset value in excess of $100 billion (Andrey et al, 2014). Transportation infrastructure such as roads, railways, sidewalks / multi-use trails, and airports are essential systems in Canada that ensure the efficient movement of people and goods, including critical services and emergency responders. While municipalities make efforts to fully integrate vital transportation networks with other modes of transportation (busses, subways, streetcars, LRT's, trains, planes, cycling) these efforts are not always successful. This is problematic for many communities. Users of this infrastructure have the expectation that it will always be operational, well maintained, safe and efficient. Any disruption within the transportation system directly affects all users that rely on it.

Roadways play a vital role in a transportation network but are highly vulnerable to disruptions and failures. Public transportation has an important role for moving passengers, who often have no other means of travel, to and from their destination. Public transportation provides access to hospitals, healthcare facilities, shelters, schools, recreation, entertainment and sporting events, shopping and much more.

On July 8, 2013, southern Ontario experienced severe thunderstorms and heavy rains that significantly affected transportation networks. During the afternoon rush hour, the intense rainfall caused major transit stoppages and delays, road closures, flight cancellations, power outages and severe flooding. The storms caused almost a billion dollars in damage (Toronto Star,

[12] Photo credit:
https://i.cbc.ca/1.2743056.1408641009!/fileImage/httpImage/image.jpg_gen/derivatives/16x9_620/viau-bus-lane.jpg

2013).While the impacts were severe, the city's transportation networks were almost completely restored by the following day (CBC News, 2013).

Intense/extreme rain is only one of the many stresses to transportation systems. Long durations of extreme heat, increased frequency of freeze and thaw cycles, heavy ice storms, high winds and others also affect transportation networks and systems. Transportation infrastructure is designed, built and maintained based on standards of the day which are developed by experts in civil engineering and engineering sciences. There are many design standard manuals currently in use.

In Canada, the legal mandate for establishing design and construction requirements for highways and highway bridges lies with the provincial and territorial governments. All provinces and territories, with the exception of Manitoba, have mandated the Canadian Highway Bridge Design Code (CHBDC) for use within their jurisdictions (CCOHS, 2017). CSA S6 applies to the design, evaluation and structural rehabilitation design of fixed & movable highway bridges and establishes safety & reliability levels that are consistent across all jurisdictions in Canada. This Code also covers the design of pedestrian bridges, retaining walls, barriers, and highway accessory structure, such as lighting poles and sign support structures (SCC, 2016).

Most provinces in Canada also have standards to meet unique conditions for that Province. In Ontario, the Transportation Association of Canada (TAC) publishes the *Geometric Design Guide for Canadian Roads* (1999, updated in 2007) and the Ministry Transportation of Ontario publishes, *The Ontario Provincial Standards for Roads and Public Works* (under the Ontario Public Standards [OPS]) (last revised 2016) which are commonly used for road design. In Ontario, the design of stormwater systems supporting transportation systems typically follows the *Ontario Stormwater Management Planning and Design Manual* (2003) and local regulation from municipalities and conservation authorities. Stormwater system design is typically based on rainfall/runoff simulation/modelling using Intensity-Duration-Frequency (IDF) relationships which are representations of the probability that a given rainfall intensity will occur at a location.

While many of these guidance documents have regular update schedules, others do not. With a changing climate, the climate design parameters in these documents can quickly become out of date. Since Hurricane Hazel hit southern Ontario on October 15, 1954, experts in Ontario have used this major storm as their “design storm” when designing new transportation infrastructure (roads, bridges, culverts etc.). Unfortunately, many of the storms we are now experiencing far exceed the design standards in use today.

## 3.4 Engineered Buildings


The review of engineered buildings in this State of Play report focuses on structures as defined in Parts 3, 4, 5, and 6 of Division B of the National Building Code of Canada (NBCC). Parts 3, 4, 5, and 6 of Division B of the NBCC applies to both site built and factory constructed buildings. This report addresses engineered public service buildings with focus on affordable housing complexes, hospitals/healthcare facilities and correctional facilities. It should be noted that while National Research Council of Canada (NRC) publishes the NBCC, it is up to each province and territory to regulate the building code for its jurisdiction. Some jurisdictions make amendments or additions to the building code, and the time between the publication of a new edition of the NBCC and its implementation across Canada varies according to the process and regulatory framework in each jurisdiction.

Codes and standards outline the requirements and accepted practices for the design, development, construction, operation and management of buildings in Canada. Standards Development Organizations, such are the Canadian Standards Association (CSA), work with technical experts, sector associations, regulators, and affected parties to establish norms that ensure the health and safety of occupants / users while protecting longevity of the infrastructure. For example, CSA has numerous technical standards and associated documents including those associated with the design of structures using concrete, steel and timber materials. Additionally there are many codes and standards for mechanical, electrical, communications and control equipment used in building infrastructure (Engineers Canada, 2008).

Existing infrastructure design parameters and thresholds are generally based upon historical weather data. Typically, past climate records are used as the basis to predict future events. Under

[13] Photo Credit: Vancouver Skyline
https://i.cbc.ca/1.1983868.1415197762!/cpImage/httpImage/image.jpg_gen/derivatives/16x9_1180/vancouver-skyline.jpg

changing climate and weather conditions, this assumption of the climate past continuing into the future will no longer apply (Engineers Canada, 2008).

Traditionally, designers of Canadian buildings made the assumption that historical climatic patterns would hold constant from the infrastructure's design and construction throughout the structure's useful life. For most buildings in Canada, their expected life cycle is at least 50 years (Engineers Canada, 2008).

While the technical provisions of the current edition of the National Building Code of Canada 2015 (NBCC, 2015) assume that the past climate will be representative of the future climate, specific text was added to NBCC editions from 1995 to the present to advise users that the assumption of stationarity will become increasingly invalid under climate change. This commentary also highlighted the need for careful consideration of climate variability in estimated values of climatic design loads (Auld et. al, 2010).

Under Budget 2016, the NRC began work to integrate climate resilience into building design guides and codes. This includes work to update and improve historical climatic design values in the NBCC. The result will be to revise Canada's NBCC by 2020 for residential, institutional, commercial and industrial facilities. Guides integrating climate resiliency into the design and rehabilitation of public infrastructure are also expected to be ready for adoption by 2020. Revisions to some areas of the NBCC, including wildfires, snow loads, and floods, are under consideration for enhanced climate change resilience. Concurrently, the Standards Council of Canada (SCC) will be identifying existing standards referenced in National Model Construction Codes, Provincial / Territorial Regulations, and Master Building Specification in order to insert climate considerations. A guide for addressing climate change adaptation is being developed for Standards Development Organizations (SDOs) to follow when developing technical infrastructure standards. SCC is working to determine what standards are necessary to more readily use current weather data and climate projections in decision-making for infrastructure lifecycles.

Ongoing studies will continue to develop methodologies that can acceptably and realistically incorporate climate change adaptation into the upcoming cycles of national codes and standards (Auld et. al, 2010).

All existing infrastructure, including engineered public buildings were designed and built to the codes and standards that existed when they were constructed. When codes and standards change, providers of public and private infrastructure face challenges in retrofitting infrastructure to meet these new standards (Feltmate and Thistlethwaite, 2012).

The Canadian Infrastructure Report Card (CIRC) provides an assessment of the health of municipal infrastructure as reported by cities and communities across Canada. The CIRC assessed the state of municipal roads, bridges, public transit, building, sport and recreational facilities, stormwater, wastewater and potable water infrastructure (FCM, 2016). It is not a prescriptive document, and does not provide recommendations for action, nor does it forecast future capital requirements resulting from municipal growth.

Almost 75% of Canada's core public infrastructure is owned and maintained by municipal governments. According to survey results, the total value of core municipal infrastructure assets is estimated at $1.1 trillion dollars. The municipally-owned buildings that were captured by the CIRC survey include: administrative buildings, children/daycare centres, community centres and cultural facilities, fire stations, health care facilities, libraries, long-term care centres, paramedic stations, police stations and shelters. The average age of municipal building infrastructure is currently about 37 years. The average physical condition rating of building assets is *good*. The average physical condition rating for health care facilities and long-term care centres are *good* and *very good,* respectively. Health care facilities are the oldest of the building types with 48% of the inventory being older than 50 years (FCM, 2016).

### 3.4.1 Multi-Unit Residential Buildings

60 Richmond East Housing Co-operative, Toronto, Ontario

In this report, the focus has been placed on affordable housing/multi-unit complexes as a specific type of residential buildings, which includes both social housing and public housing as per the scope of the project. For engineered affordable housing complexes, this includes row houses, apartments and condominiums buildings.

Public housing in Canada is provided under either a federal, provincial, or local program designed to provide subsidized assistance for low- to moderate-income people. Increasingly provided in a variety of settings, public housing used to be one or more blocks of low-rise and/or high-rise housing operated by a government agency. Canadian Mortgage and Housing Corporation (CMHC), and Provinces and Territories administer the existing social housing stock in Canada, under several programs (CMHC, 2016c).

Currently, there is no readily available Canada-wide or provincial inventory of affordable housing complexes that contains information on facility's age and history, building and construction type, current conditions etc. Housing data are available, such as those published by CMHC, but these data usually only deal with information associated with individual rental units and not on the

[14] Photo credit: https://www.canadianarchitect.com/features/60-richmond-east-housing-co-operative/

building in its entirety. The methodologies, materials and technologies in the design and construction of affordable housing complexes are similar to typical residential buildings.

The average age of Canada's 600,000 social housing units is currently about 40 years (FCM, 2015a). Budget 2016 (Federal) committed $1.278 billion over the next 2 years to capital repairs which is intended to assist in the repair and retrofit of existing units, and build more affordable housing, including housing for Canada's seniors (FCM, 2015a). In Toronto, 400 social housing units sit empty because of the work that needs to be done to make them habitable. Without federal investment, Toronto estimates that it will lose 7,500 units by 2023 (FCM, 2015a). Similarly, in Vancouver there are 4,000 Single Room Occupancy units that require immediate investment, plus the City has identified municipal land that can be developed immediately with federal funding (FCM, 2015a).

The stock of lower-rent dwellings is shrinking as properties are demolished for new condominium development. This is compounded with low rates of rental apartment construction. In 2011, condominiums made up of 11 per cent of the rental market in Canada. However, these are often not affordable for lower and moderate-income households (FCM, 2015b).

### 3.4.2 Hospitals / Healthcare Facilities


Healthcare facilities are vital assets to communities. This is especially true when disaster strikes. Secure and resilient hospital infrastructure protects patients, visitors, and staff from hazards and allows them to continue to provide life-saving medical care in disasters. As of December 2014, there are 1461 hospitals in Canada according to Statistics Canada[16]. This survey data does not provide any information in regards to building and construction type and current conditions of the facilities.

[15] Photo credit: http://everydaytourist.ca/2013/2013/11/18/fun-ideas-of-downtown-calgary

[16] https://www.ic.gc.ca/app/scr/sbms/sbb/cis/establishments.html?code=622&lang=eng based on NAICS (North American Industry Classification System) code 622 - Hospitals

In February 2016, a survey of Canada's hospitals and healthcare facilities revealed 444 distinct infrastructure projects valued at $5.9 billion required to repair and maintain existing structures. Of these projects, 91% were regarded as repairs and/or retrofits to currently existing facilities, and 9% of the projects were for new buildings and expansions (ref. Table 3-2). In addition, it is estimated that as much as $28 billion in hospital maintenance costs have been deferred (HealthCareCAN, 2015).

**Table 3-2 Hospitals / Healthcare Facilities Infrastructure Projects by Purpose**

(Source: HealthCareCAN, 2016)

| Projects by Purpose | # (%) of all Projects | Cost of Projects |
|---|---|---|
| Repairs and Energy Retrofits | 363 (82%) | $ 2,090,292,599 |
| New Buildings | 42 (9%) | $ 2,388,100,000 |
| Expansions | 39 (9%) | $ 1,502,577,549 |
| *Total* | *444 (100%)* | *$ 5,980,950,148* |

As of 2006, Ontario's hospital buildings were, on average, more than 40 years old and required significant investment to modernize and upgrade the facilities and expand capacity (Ontario, 2010). Green facility design and environmentally sustainable practices (e.g. using green cleaning products, making use of natural light, renewable energy sources) are emerging trends within health care facility design and construction. LEED is a green building rating system that provides a suite of standards for environmentally sustainable construction (Ontario, 2010).

From an Ipsos Reid (2015) poll commissioned by HealthCareCAN to conduct survey research among the Canadian public on a variety of issues confronting the health care system today, it was determined that residents of Quebec are most likely to prioritize investment in ageing hospitals over roads and bridges, while residents of Saskatchewan and Manitoba are least likely.

The Canadian Standard for Health Care Facilities (CSA Z8000) is the standard that provides requirements and guidance for the planning, design, and construction of Canadian healthcare facilities. It is intended to be used by all facilities providing health care services regardless of type, size, location, or range of services. This Standard was developed to provide a consistent methodology and practical requirements for health care facilities across the country. CSA Z8000 was developed to complement existing standards and codes by providing a set of over achieving requirements for health care facilities and reference to specific standards and codes as appropriate. As a design and construction standard, CSA Z8000 does not specify requirements for operational models, policies, procedures, etc. Those elements are addressed in other standards, guidelines, and tools provided by CSA and other organizations (Ontario, 2012).

The CIRC provides an assessment of the health of municipal infrastructure as reported by cities and communities across Canada. Health care facilities are the oldest of the building types surveyed with 48% of the inventory being older than 50 years. The average physical condition rating for health care facilities and long-term care centres are *good* and *very good* respectively (FCM, 2016), however, as outlined in Table 3-2 maintaining this condition rating is expensive.

The assessment of the safety, preparedness and resiliency of hospitals identifies priorities for remedial action, including cost-effective retrofitting and supports evidence informed decision-making to reduce health risks from climate change. New hospitals can be safeguarded by risk-sensitive siting, design and building in compliance with building codes. Emergency planning, staff training and exercises build adaptive capacity to manage risks and respond effectively.

### 3.4.3 Correctional Facilities


The Correctional Service of Canada (CSC) is the federal government agency responsible for administering sentences of a term of two years or more, as imposed by the court. CSC is responsible for managing institutions of various security levels and supervising offenders under conditional release in the community (Government of Canada, 2013).

Correctional Service Canada (CSC) manages and maintains[18]:

- 43 institutions
  - 11 clustered institutions
  - 2 maximum/medium/minimum security level units
    - 9 medium/minimum security level units
    - 6 maximum security institutions
  - 9 medium security institutions
  - 5 minimum security institutions
  - 12 multi-level security institutions
- 92 parole offices
- 15 Community Correctional Centres
- 200+ Community Residential Facilities

Each major correctional institution is operated like a small community. There are living units, offices, program areas, buildings, and spaces designed for spirituality, healthcare, employment, recreation and other services. The nature of the work and the need for security make these

[17] Photo credit: http://www.bondfield.com/portfolio/correctional-facilities/central-ontario-east-correctional-facility.php
[18] http://www.csc-scc.gc.ca/publications/005007-3024-eng.shtml

facilities unique and complex (Government of Canada, 2013). CSC is currently investing in infrastructure renewal which includes building new living units in many of its existing institutions and expects to add more than 2,700 accommodation spaces to penitentiaries across Canada in the coming years (Government of Canada, 2013).

Currently, there is no readily available comprehensive, Canada-wide or provincial inventory of correctional facilities which contain information on facility's age and history, building and construction type, current conditions etc. With the exception for the need for security, the methodologies, materials and technologies utilized in the design and construction of buildings within correctional institutions are similar to typical buildings with the same occupancy type. This is further reinforced by the current design trend where correctional facilities are being transformed from places of punishment to places of confinement in which societal values of human dignity and effective rehabilitation can be achieved (Parkin Architects, 2016).

### 3.4.4 Other Engineered Buildings

Other engineered buildings whether industrial, commercial, institutional (such as retirement homes, schools, universities, community centers, etc.) have not been directly considered in this report at the direction of the IBWG. However, as noted for correctional facilities, the methodologies, materials and technologies utilized in the design and construction of buildings are considered similar to typical buildings with the same occupancy type. A key consideration with regard to these types of structures is placement within the community from a land use planning perspective.

## 3.5 Non-Engineered Buildings

[19] Photo Credit:
https://www.thestar.com/content/dam/thestar/life/homes/2009/02/10/loss_of_confidence_swamps_house_market/house_prices_expected_tofall.jpeg.size.custom.crop.1086x724.jpg

The review of non-engineered buildings in this report focuses on structures such as those defined in Part IX of the National Building Code of Canada (NBCC). Part IX of the NBCC applies to all buildings of three (3) storeys or less in building height, having a building area not exceeding 600 $m^2$. Part IX of the NBCC applies to both site built and factory constructed buildings.

This report considers non-engineered buildings having residential occupancies (Group C). Although Part IX also applies to Group D (Business and Personal Service Occupancy), E (Mercantile Occupancy) and F (Divisions 2 and 3) (Industrial; referring to High and Medium hazard industrial occupancies) occupancies, climate change adaptation issues related to these occupancies are not included in this report.

Part IX of the NBCC also applies to Farm Buildings, but for this State of Play report Farm/Agricultural buildings are considered under the purview of the Agricultural Working Group, and therefore not included in this review. As noted, Part IX of the NBCC is specific to buildings of three (3) storeys or less in building height, having a building area not exceeding 600 $m^2$. However, no statistics are gathered through the census or other data collection activities that capture this information explicitly in relation to building construction in Canada.

In Canada, typical residential construction is based on wood-frame approaches. Current wood-frame technology has evolved over many years of development and research by the National Research Council (NRC), Canada Mortgage and Housing Corporation (CMHC), industry and others. A well-designed and constructed, wood-frame building has many attributes including ease of renovation, durability, and others which make it easily adaptable to potential climate change impacts for all climates in Canada ranging from hot and humid to extremely cold (CMHC, 2014). In the few Canadian locations where risk is high, bracing to resist lateral load, due to earthquake or wind, must be designed in accordance with NBCC Part 4 or good engineering practice such as that provided in the *Engineering Guide for Wood-Frame Construction* (CWC, 2009).

Construction of single family homes dominated new construction in Canada in the 1950s. The evolution of the Canadian household has seen bigger homes with fewer people living in them. Average living space in 2009 was 11 percent greater than that in 1990, yet the number of individuals per household fell from 2.8 in 1990 to 2.5 in 2009 (NRCan, 2012). This trend, coupled with population growth, has spurred the market for additional housing. With the increasing wealth of Canadians (StatsCan, 2006), more energy is being consumed to cool homes in the summer months (ref. Figure 3-4).

Since 2012, construction of apartment buildings has represented the largest portion of residential dwelling construction in Canada (StatsCan, 2016a). In 2014, apartment construction exceeded construction of any other dwelling type in Canada's three largest metropolitan areas (ref. Table 3-3) and construction of new single-family dwellings has been in decline since the early 2000s (StatsCan, 2016a).

As noted previously, the value of building permits issued in Canada totals about $1.7 trillion since 1965 with about 50% of this value representing residential permits. Permits for over 10 million dwellings have been issued since 1965 with about 34% issued since 2000. About 11% of occupied dwellings in Canada were constructed in the period from 1945 and earlier. About 60% are about 25 years to 50 years old and the remainder are less than about 25 years old (CMHC, 2016b).

New construction adds about 120,000 new buildings[20] each year and over the period 2011 to 2016, the value of residential building permits has been steadily rising at a rate averaging about 5% annually (StatsCan, 2016b).

**Figure 3-4 Evolution of Canadian Households 1990 to 2009**

(Source: NRCan, 2012)

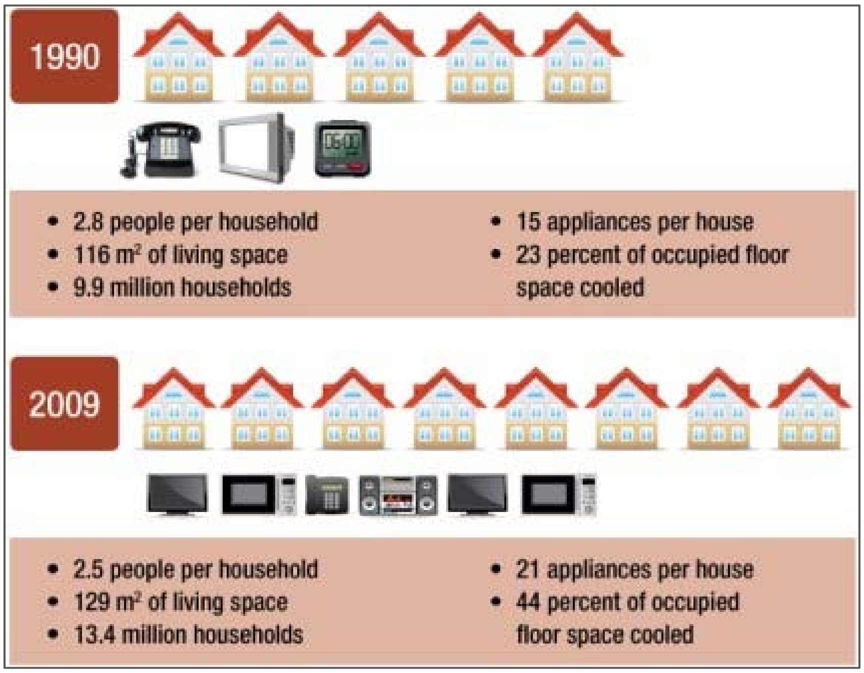



**Table 3-3 Apartment and Single Family Homes Construction as a Percentage of all Dwelling Types (2014)**

(Source: StatsCan, 2016a)

| Location | Apartments | Single Family Homes |
|---|---|---|
| Toronto | 54% | 27% |
| Montréal | 75% | 16% |
| Vancouver | 67% | 16% |

[20] Averaged over the census years 1991, 1996, 2001, 2006 and 2011 for categories Single- and semi-detached house, Row house, Apartment detached duplex, and other single-attached house. Source: CHMC, 2016a.

## 3.6 Other Infrastructure

As noted previously, the scope of this State of Play report focuses on infrastructure and buildings within the purview of the IBWG, as well as infrastructure not included within the focus of any of the other Adaptation Platform Working Groups. Telecommunications was identified by the IBWG as "Other Infrastructure" not being addressed by any of the other Working Groups.

### 3.6.1 Telecommunications

Telecommunications refers to electronic transmission of information over distance including voice, data and images. This includes telephones (cellular and landline), cable television services, and internet services. Businesses, financial transactions, emergency services, and health care information systems are among the many sectors that rely on telecommunications to function (City of New York, 2013). Telecommunications infrastructure includes critical facilities that handle distribution and switching, underground and overhead cable connections, cell sites on towers or on freestanding buildings, and equipment in homes or buildings that connects the network to individual customers (City of New York, 2013).

Telecommunications infrastructure consists of networks, systems and assets that enable and manage the transmission, receipt, storage, manipulation of voice and data on and across various electronic devices. These devices include individual components, systems devices and end-use systems. Individual components include copper and fiber-optic cables, antennas, exchanges, routers, wireless access points, network switches. It also includes end-user devices like computers, phones, PDAs, SCADA control devices etc. (Horrocks, et al, 2014). The accumulated capital investment across the Canadian telecommunications sector was $119.2 billion in 2013 (ISEDC, 2016).

[21] Photo Credit: ICT Infrastructure - http://exportwise.ca/wp-content/uploads/2016/07/ITAC.jpg

Public Safety Canada identifies telecommunications, along with nine (9) other infrastructure sectors, as critical infrastructure (Public Safety Canada, 2016). Critical infrastructure is essential to Canadians and the effective functioning of government. Disruptions of critical infrastructure have the potential to result in "catastrophic loss of life, adverse economic effects, and significant harm to public confidence" (Public Safety Canada, 2015). Telecommunications facilitate the functioning and connectivity of all other critical infrastructure.

Some Canadian telecommunications facts (CWTA, 2016):

- $2.9 billion in capital investment by Canadian wireless network operators in 2014
- 29.6 million wireless subscribers in Canada
- Canada's wireless carriers offer coverage to more than 99% of Canadians
- Canadian wireless phone subscribers number over 30 million
- In Canada, mobile data traffic will grow 600% from 2015 to 2020, a compound annual growth rate of 42%
- Data consumption increased by 44% in 2014-2015
- In 2014, 23.7% of households reported using a cell phone exclusively, up from 20.4% in 2013

Climate change brings vulnerabilities for the telecommunication systems including interruptions and reduced quality of services. Direct impacts include damage or disruption to the structures or networks and indirect impacts can occur from disruptions to the supply chains that feed into the main local network (Horrocks et al, 2014). Temperature increases can directly burden cooling equipment and stress equipment, shortening their useful life. Indirectly, increases in temperature lead to greater demands for energy for cooling, leading to power outages that in turn disrupt the telecommunications network infrastructure (Riverside Technology, 2014). Increased precipitation increases the risk of direct damage from flood, erosion, or ice to telecommunications infrastructure, while decreased precipitation can increase the risk of damage from land subsidence and heave, as well as wildfires (Riverside Technology, 2014). Changes in humidity can increase risks of corrosion for some types of equipment, and coastal equipment is at higher risk of corrosion, inundation, or erosion because of sea level rise (Riverside Technology, 2014). Increased frequency and intensity of extreme events can directly damage above-ground transmission infrastructure, through heavy winds and lightning strikes (Riverside Technology, 2014). Indirectly, extreme events can disrupt air, land and sea transport as well as manufacturing operations, impacting local and global supply chains (Riverside Technology, 2014).

The primary causes for telecommunications infrastructure failure during disasters are a result of:

- Physical destruction of network components that are exposed to climatic hazards
- Disruption of the supporting network infrastructure such as the electrical distribution system
- Network congestion

Major disasters are the most intense generators of telecommunications traffic (Townsend & Moss, 2005). Because telecommunications providers share infrastructure, failure of an asset, such as a cut cable or flooded facility, can cause an outage for thousands of customers. In 2012, Hurricane Sandy caused telecommunications outages in New York, both as a result of loss of electrical power to telecommunications infrastructure (generally short-term outages) and as a result of flooding to critical facilities (generally long-term outages) (City of New York, 2013). Flooding caused damage to electrical switchgear, backup generators, and fuel storage containers at a number of facilities, and the pumps in many of these facilities were not designed for the volume and salinity of the floodwaters (City of New York, 2013). In some cases, just removing the water from some facilities took up to five days. Outages at some critical facilities lasted between 24 hours to 11 days, while some residential buildings were still without service six months after the storm (City of New York, 2013).

The dependence of telecommunications infrastructure on the electrical distribution system is a vulnerability for this sector (Riverside Technology, 2014). Recognizing this dependence is key to improving the resilience of telecommunications systems, and efforts in this sector can be coordinated with efforts by utilities.

The cascading effects that result from the loss of telecommunications can be difficult to anticipate, especially when trying to predict the aftermath of such intensive storms as Hurricane Sandy. The reliance and interoperability of other critical infrastructure on the telecommunications sector would suggest that there is a need to better understand the connectivity of the supply chains and build resiliency to mitigate climate impacts. The gradual impacts of climate change (such as consistently higher temperatures) must also be considered in adaptation measures (Riverside Technology, 2014). The type and age of the technology and infrastructure must also be accounted for, as it will influence its susceptibility to different climate change impacts, so a range of solutions will be required to improve resilience (Riverside Technology, 2014).

The following organizations have some level of national responsibility regarding climate risks in the telecommunications sector in Canada[22]:

Innovation, Science and Economic Development (ISED)

ISED Canada works with Canadians in all areas of the economy and in all parts of the country to improve conditions for investment, enhance Canada's innovation performance, increase Canada's share of global trade and build a fair, efficient and competitive marketplace. ISED oversees the Canadian Security Telecommunications Advisory Committee (CSTAC).

Canadian Security Telecommunications Advisory Committee (CSTAC)

CSTAC was established in November 2010 in support of two key Government of Canada initiatives, the National Strategy for Critical Infrastructure and Canada's Cyber Security Strategy.

CSTAC allows the private and public sectors to exchange information and collaborate strategically on current and evolving issues that may affect telecommunications infrastructure, including cyber security threats. Membership includes senior executives from the Canadian telecommunications industry, Industry Canada, Communications Security Establishment Canada, Public Safety Canada, Canadian Security Intelligence Service and the Privy Council Office.

[22] The description of the telecommunications organizations ISED, CSTAC and CTRWG provided by David MacLeod, Senior Environmental Specialist, City of Toronto.

CSTAC's telecommunications industry members developed a Canadian Telecommunications Service Providers' (TSP) Security Best Practices, a series of voluntary measures designed to provide guidance to service providers on implementing the appropriate level of network security required to meet their customers' needs. These best practices are intended to be a baseline against which service providers can evaluate their existing network security policies. This document will be regularly reviewed and assessed against industry developments and technological advances to ensure they remain relevant and useful. There is an opportunity to increase the content of this document better taking into account more frequent extreme weather, as well as the high probability that weather patterns will continue to change, exerting more frequent stresses on telecommunications equipment in Canada. There is also an opportunity to consider how critical infrastructure that supports the telecommunications sector (e.g. electricity) may be more frequently disrupted, resulting in impacts on the telecommunications sector.

Currently, a national all hazards risk assessment is being conducted under the supervision of CSTAC for the telecommunications sector. Weather is one of the risks being considered. This document should provide some insights regarding the status of the telecommunications sector's resilience to extreme weather associated with climate change.

Canadian Telecom Resilience Working Group (CTRWG)

The CTRWG, reporting to CSTAC, is a new organization that replaces the former Canadian Telecom Emergency Planning Association. CTRWG is involved with two major aspects: engineering solutions to reduce telecommunications downtime and emergency response. This group operates in parallel to the Canadian Telecom Cyber Protection Working Group, which also reports to CSTAC.

# 4.0 Vulnerabilities, Impacts, Interdependencies, Barriers and Gaps

## 4.1 Vulnerabilities and Impacts

This chapter focuses on key climatic variables that are anticipated to influence (and may have already influenced) the infrastructure systems considered by the State of Play report. Assessing the current state of public infrastructure under these climatic scenarios provides an understanding of existing vulnerability and potential future vulnerabilities to better understand potential risks in light of climate change.

Table 4-1 has been developed from a review of numerous literature sources and provides an overview of events and processes, which may likely be influenced or caused by climate change and their potential infrastructure impacts. This list is not intended to be exhaustive, however it illustrates the potential for climate change to seriously impact infrastructure and buildings.

**Table 4-1 Projected Infrastructure Vulnerabilities to Climate Change[1,2]**

| Projected Changes | Potential Infrastructure Impacts |
|---|---|
| **Temperature**<br><br>• Increase in annual and seasonal air temperature<br>• Increase in number of hot days and heat waves<br>• Decrease in number of extreme cold days<br>• Reduced diurnal temperature range over most land areas<br>• Loss of permafrost<br>• Increase in evapotranspiration<br>• Increase frequency of freeze-thaw cycles<br>• Increased humidity<br>• Increased frequency of drought conditions | ▶ Seasonal shifts in energy demand<br>▶ Planning problems due to less reliable forecasting<br>▶ Permanent submergence of some coastal areas/decrease in riparian property<br>▶ Saltwater intrusion into aquifers<br>▶ Decrease in water quality, potential increase in toxic algae blooms<br>▶ Increased coastal erosion with increased exposure to winter storms due to reduced ice cover protection to winter storms<br>▶ Potential increase in disruption to/failure of electrical systems, communications towers<br>▶ Soil instability, ground movement and slope instability affecting infrastructure<br>▶ Triggered instability of embankments and pavement structures<br>▶ Increased frequency, duration and severity of: thermal cracking, rutting, frost heave and thaw weakening<br>▶ Pavement softening/reduction in the maximum loads that can be safely transported<br>▶ Rail buckling (speed reductions, spillage, derailment, scheduling delays, sensor malfunction)<br>▶ Change in timing/duration of seasonal load restrictions and winter weight premiums<br>▶ Increased challenges in pavement construction process<br>▶ Shortened life expectancy of highways, roads and rail<br>▶ Drier conditions affecting the life cycle of bridges and culverts<br>▶ Increased flow of streams and rivers<br>▶ Augmentation of Urban Heat Island Effect<br>▶ Increased reliance on cooling system and thus cost for space cooling<br>▶ Increased heat related health and safety risks to exposed workers<br>▶ Location/density of communications masts may become sub-optimal as wireless transmission is dependent on temperature (refractive index)<br>▶ Impacts on radio-frequency propagation quality if vegetation type changes<br>▶ Reduce costs of space heating in buildings and thus reduced energy cost for space heating<br>▶ Reduced snowfall impacts on masts, antennae, etc. requiring less maintenance |

| Projected Changes | Potential Infrastructure Impacts |
|---|---|
| | ▸ Less frequent requirements to cope with snow-melt water surge (flood) problems<br>▸ Changes in corrosion rates related to humidity<br>▸ Changes in requirements for de-humidification to maintain internal environments within tolerance ranges of devices<br>▸ Increased risk of subsidence, reduced stability of foundations, and tower structures<br>▸ Traffic signal malfunction |
| **Wind** | ▸ Possible increase in speeds, changing patterns, shifting storm tracks<br>▸ Increasing damages to built infrastructure from wind storms<br>▸ More intense winter storms could result in a more dynamic shoreline zone and sand movement<br>▸ Increased soil erosion affecting infrastructure<br>▸ Closures/obstruction due to debris |
| **Precipitation**<br><br>• Increase in annual average precipitation<br>• Increase/decrease in seasonal average precipitation<br>• Increase in frequency and severity of drought<br>• More precipitation falling as rain/freezing rain rather than snow<br>• Potential increase in ice storms / freezing rain events<br>• Increased risk of flooding where precipitation increasing<br>• Increase in forest fire hazard where precipitation decreasing | ▸ Increase in sanitary sewer direct discharges (CSO's)<br>▸ Potential increase in disruption to/failure of electrical systems<br>▸ Increase in waterborne disease outbreaks<br>▸ Water availability/low water concerns during more frequent and severe periods of drought<br>▸ Increase in erosion potential and sediment transport<br>▸ Less water available for agriculture, hydropower production, recreation<br>▸ Increased soil erosion<br>▸ Impacts to municipal water intakes and discharge pipes (lowering lake levels)<br>▸ Negative impacts to inland / ocean shipping/navigation/coastal infrastructure<br>▸ Shoreline retreat, increase in riparian property boundaries<br>▸ Capacity of culverts and storm sewer systems are more frequently exceeded; road damage, bridge washouts, underpass and basement flooding, increased repair bills and insurance costs<br>▸ Causeways, bridges and low-lying roads have a high risk of being inundated or damaged<br>▸ Reduced building components structural integrity through mechanical, chemical and biological degradation / Accelerated deterioration of building facades<br>▸ Premature weathering of input materials<br>▸ Increased fractures and spalling in building foundations<br>▸ Decreased durability of materials<br>▸ Increased efflorescence and surface leaching concerns<br>▸ Increased mold growth<br>▸ Slope stability and integrity of engineered berms are also vulnerable to extreme precipitation<br>▸ Wharves and other coastal infrastructure to be rebuilt, moved or raised to avoid inundation<br>▸ Existing moorings will require re-construction<br>▸ Increased risk of basement and localized flooding / failure of urban stormwater infrastructure, high rates of rainfall derived inflow/infiltration resulting in sewer backup events<br>▸ Increased corrosion in metals or deterioration in concrete<br>▸ Summer taste/odour problems in municipal water supply<br>▸ Capacity of stormwater infrastructure more frequently exceeded<br>▸ Increased capacity of wastewater treatment facilities required<br>▸ Urban drainage systems could fail, causing problems such as sewer backups and basement flooding<br>▸ Communications towers can experience structural damages under heavy ice accretion loads or ice-fall damage from ice shedding (ice falling from the structure with melting temperatures), and in the most server ice storms, collapse<br>▸ Drier conditions affecting the life cycle of bridges and culverts.<br>▸ Road blockage/disruptions<br>▸ Bridge scour/closures<br>▸ Flooding of roads, bus storage depots, etc |

| Projected Changes | Potential Infrastructure Impacts |
|---|---|
| **Extreme Weather**<br><br>• Increased frequency and/or severity of heavy precipitation events<br>• Drought<br>• Hurricanes / Tropical Storms<br>• Hail<br>• Wildland fire<br>• Increase in coastal storm surge / risk of flooding | ▸ Increased damage to existing infrastructure and property / catastrophic failure<br>▸ Increasing number of lightning strikes<br>▸ Reduction of design safety margins<br>▸ Reduced service life and functionality of components and systems<br>▸ Increased repair, maintenance, reserve fund contingencies and energy costs<br>▸ Increased water demands and pressure on infrastructure / water apportioning issues<br>▸ Loss of potable water and increased water quality problems<br>▸ Increased force exerted on docks<br>▸ Land-based installations, such as oil storage reservoirs or storage facilities may need protection with seawalls to avoid damage<br>▸ Increased risk of flooding of low-lying infrastructure and underground facilities<br>▸ Increased erosion and flood damage to transport structures which may expose other infrastructure<br>▸ Reduced quality of wireless communication services with higher rainfall rates |

**Notes:**

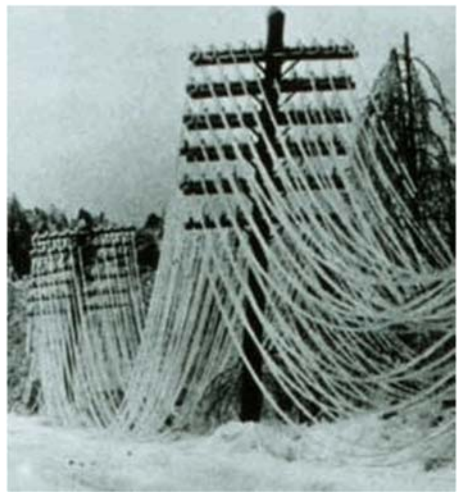
1. The information above is not meant to be a complete listing but, rather, only to be some of the more frequently identified direct and indirect impacts projected as a result of climate change.
2. Sources: AMEC, 2006; BC, 2002; C-Cairn, 2006; NRCAN, 2004; IISD, 2013; HMGovernment, 2011; Horrocks, et al, 2014

## 4.2 Interdependencies

A community is a complex and dynamic system of systems in which cyber, physical, social, and organizational components are interconnected and interact in a dynamic nonlinear, probabilistic, and spatially distributed fashion (Moselhi et al, 2005). These interconnected systems suffer from increased risk simply because of their proximity to one another (O'Rourke, 2007). Damage to one component, such as a watermain or culvert, can quickly cascade into damage to surrounding components, such as electric and telecommunications cables, gas mains, sewage systems, etc., with compounding consequences. Unfortunately, much of this interdependent infrastructure is hidden underground, at times with unknown or approximate location and for which the condition of components is not known. The proximity of aging, weakened infrastructure to other important facilities, such as high-pressure gas mains and underground electric power vaults, is frequently unrecognized, increasing the potential for unanticipated accidents for which no preparations have been made (O'Rourke, 2007). Water supply, wastewater and solid waste disposal, power (electric power, gas and liquid fuels), transportation, and information and communications technologies (ICT) are termed "lifeline systems" (O'Rourke, 2007, Nash, 2009) without which buildings, emergency response systems and other infrastructure cannot perform their intended function. These interdependent systems work together to provide the essential services of communities (Nash, 2009) and impact to one infrastructure can directly and indirectly affect other infrastructure, impact large geographic regions, and cause impacts across the national and global economy (Rinaldi et al, 2001).

It should also be pointed out that interdependences are not always apparent. For example, the climate change vulnerability assessment completed by the City of Montreal highlighted a link between leakage in the drinking water network and deterioration of sewer lines (City of Montreal, 2015). Recognizing the interdependencies amongst different systems, and taking a broader approach to assessment of the state of infrastructure, allows fulsome appreciation of the influence each system has on others, as well as the compounding vulnerability and risk associated with future climatic predictions. However, from an outcome-measures perspective, there are challenges with making this type of assessment given, for example, the nature of interdependent infrastructure (e.g., underground municipal water/wastewater might intersect with provincial transit infrastructure). Unfortunately, metrics that describe the operating states of interdependent infrastructure and scale of interdependency-related disruptions have been lacking (Rinaldi et al, 2001). The Facility Condition Index (FCI) may be a measurement option in this regard. The FCI is a key performance indicator[23] which is used to objectively quantify and evaluate the current condition (i.e. physical health) of a facility. This measure could be augmented to include interdependence issues.

## 4.3 Vignettes Demonstrating Climate Change Vulnerabilities, Impacts and Interdependencies



**Eastern Canada Ice Storm**[24]: The January 1998 ice storm was a combination of five smaller successive ice storms spanning from eastern Ontario, southern Quebec, Nova Scotia, and northern New York to central Maine. The storm caused road closures, power outages to nearly 1.6 million customers in Quebec and Ontario, claimed as many as 35 lives, injured 945, and displaced about 600,000 people. In Quebec, the storm caused a huge power failure, disruption of water supply and sanitation systems, and traffic chaos. Without power and water, fighting fire was not an option. (Moselhi, 2005). Throughout the storm and its immediate aftermath, approximately 2.6 million people, 19 per cent of all Canadian employees, were impeded or prevented from travelling to work. The total financial cost of the storm has been estimated at $5.4 billion (Canadian Encyclopedia, n.d.). The ice storm led to the largest deployment of Canadian military personnel since the Korean War with over 16,000 Canadian Forces personnel deployed, 12,000 in Quebec and 4,000 in Ontario at the height of the crisis (Abley, 1998; Operation Recuperation, 2005). The storm's impact may go beyond the immediate event itself; researchers at McGill University have been tracking the potential health impacts of children whose mothers endured stress (while pregnant) during the ice storm. Researchers found that changes in the genes of these babies, now teenagers, may put them at a greater risk to develop asthma, diabetes or obesity in the future (McGill University, 2014). Although nothing of this scope has occurred since, there have been other major and highly damaging ice-storms since the 1998 storm: one in the Toronto area in 2013, and a lesser one in Montreal in 2015 (RCI, 2017).

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[23] http://www.assetinsights.net/Glossary/G_Facility_Condition_Index.html
[24] Photo credit: canadaalive.wordpress.com/2013/12/27/snapshot-ice-storm-98/

**Growing Dependence**[25]: The growth of the Internet, the increasing number of "mission critical" business functions that rely on communication networks and the emergence of general societal dependencies on communications, all make the survivability of the physical network that the information society depends on essential and of paramount importance. Further, communicating information during and following an emergency event or disaster to relevant parties is a key priority as telecommunications infrastructure links emergency management and response agencies and organizations. Despite considerable efforts at physical protection of cables, statistics show that metropolitan networks annually experience thirteen (13) cuts for every 1600 kilometres of fiber, and long haul networks experience three (3) cuts for 1600 kilometres of fiber (Moselhi, 2005). Regardless of the increasing reliability and resiliency of modern telecommunications networks to physical damage, the risk associated with communications failures remains serious because of emergency operations dependence on these tools. When communication networks fail, the impact can be widely felt. Whether these systems are completely or just partially disrupted, communications systems during a disaster can be the difference between life and death for those affected (Richards, 2015).

**Impacted Vulnerable Populations:** Following the July 8th, 2013 GTA storm, a senior citizen's basement apartment was destroyed in the storm's aftermath leaving individuals to reside in tents. The basement apartment was covered in mould and mildew and was not livable for a period of time. I've lost everything," said Hills, "I don't have insurance. I'm unemployed at the moment. I've had no choice but to live here." Hills, who suffers from diabetes, is one of hundreds of residents along Cooksville Creek who were displaced from their homes (Gheciu, 2013). This example highlights the impact of infrastructure vulnerability to municipal services and vulnerable populations. Vulnerable populations living near a watercourse are more at risk as emergency services may not be able to reach them in time during an extreme event with the Creek responding within 10 minutes (Gheciu, 2013).

Ken Hills, 60, stands in front of a tent that has served as his home since last week's devastating flood destroyed his basement apartment (Gheciu, 2013).

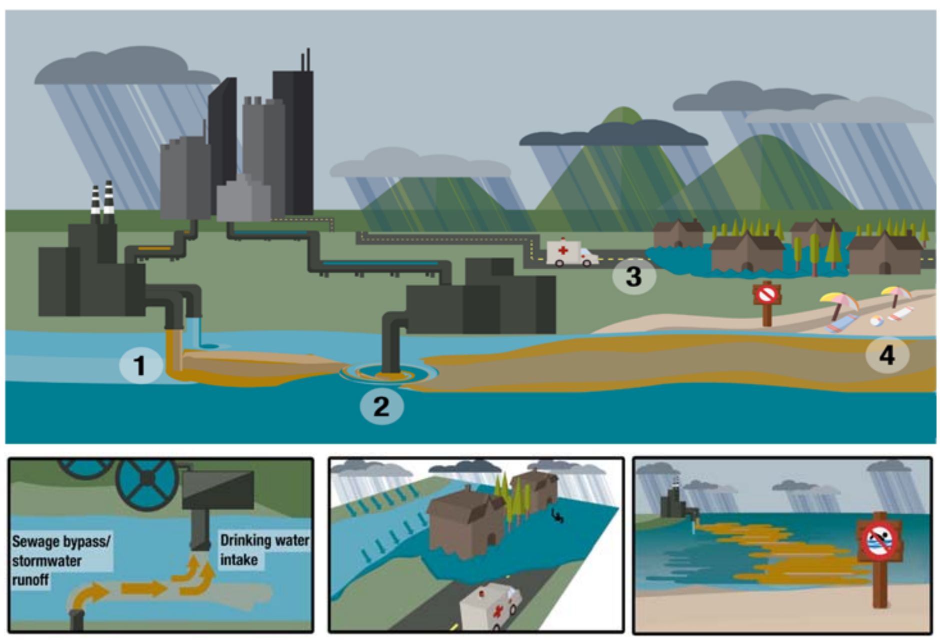
Another example is that Toronto is expecting a fivefold increase in three-day heat waves by 2049 leaving the City's vulnerable populations, (frail, elderly and socially isolated), at potentially great risk of heat-related health impacts. Toronto Public Health has researched options to reduce risks

[25] Photo credit: www.vacuumtruckexchange.com//images/page_upload/10/vacuum-excavation-2.jpg

from extreme heat to vulnerable populations living in multi-residential buildings concluding that numerous options are available (ICLEI, 2015).

**Extreme Rainfall**: An extreme rainfall event on August 19, 2005 in Ontario was the catalyst for the collapse of a section of Finch Avenue West in Toronto, Ontario. In the span of three hours, 153 mm of rain fell, a 78 m stretch of Finch Avenue West cratered, the Black Creek culvert collapsed, a 48 m section of trunk sanitary sewer was lost, releasing raw, uncontrolled sewage into Highland Creek for three (3) days. Basement flooding in private residences was unprecedented. The damages associated with this event ranks it as one of the most expensive natural disasters in the province's history, with private insurance payouts approaching $740 million (IBC, 2016). Figure 4-1 provides a snapshot of some of the key infrastructure linkages and interactions between types of water infrastructure under a short duration, high intensity rainfall event scenario to provide context for these social vignettes.

**Figure 4-1 Water Infrastructure Linkages during a Short Duration, High Intensity Rainfall Event**




1. Wastewater treatment sewage bypass/combined sewer overflow.
2. Drinking water intake drawing heavily polluted water requiring extra treatment to meet drinking water standards.
3. Riverine flooding can occur during an extreme rainfall event which causes high flows in watercourses resulting in sewer system back-up and flooding of basements and roadways. Flooding of roadways can keep emergency service vehicles from getting to vulnerable populations.
4. Wastewater treatment plant sewage bypass and/or combined sewer overflows can result in bacterial outbreaks resulting in beach closures due to risk of severe health impacts.


(AMEC, 2015)

**Flooding and Land Use Planning:** The community of Placentia, NL is generally located in a 20-year flood zone. Floods in this community are caused by a combination of high tides, storm surge and high wind and waves. To reduce flood damage, an embankment was built along the Placentia Bay shore, and a sea-wall was built along the harbour. Sea level rise will make it increasingly difficult to protect Placentia from floods. It is postulated that the 100-year flood zone for Placentia may be the 1 in 20 year flood zone by 2050, with areas formerly outside the 100 year zone now prone to flooding. This may include the new Laval High School constructed in 2010. As the flood protection/mitigation measures, including the sea wall and berm, have been designed based on protection from the historic 100-year predicted flood, it is possible that these protective features are likely to be inadequate by 2050 (Batterson and Liverman, 2010).

Source: Google Earth Pro

**First Nation's Community and Emergency Response:** As a result of weather conditions in Spring 2013, the Spanish River watershed was experiencing high water levels with the potential to approach the historic 100 year flood level. High water levels in the Spanish River had the potential to top the banks along low points of the road which serves as the main access road for the community of Sagamok in the Sagamok Anishnawbek First Nation. If flooding had occurred, there was an expectation that the community would become isolated for a number days until floodwaters receded. Emergency measures were to be put in place to assist vulnerable residents of the community if they were to stay, or evacuate them in advance of flooding. These types of events are expected to increase in frequency as a result of climate change.


Source: CBC News, 2014b)

**The price of not identifying vulnerabilities and do nothing:** Halifax pumped raw sewage into the harbour for decades before opening a $55 million treatment plant in 2008, followed by the opening of harbour beaches (CBC News, 2014b).

A heavy rainfall event in January 2008 caused a series of cascading mechanical and electrical failures resulting in complete plant failure and shutdown in Halifax's new sewage treatment plant. Electrical overload of the backup generators due to design failure resulted in its shutdown causing the pumps and tunnel gate to fail causing sewage to bypass into the harbour.

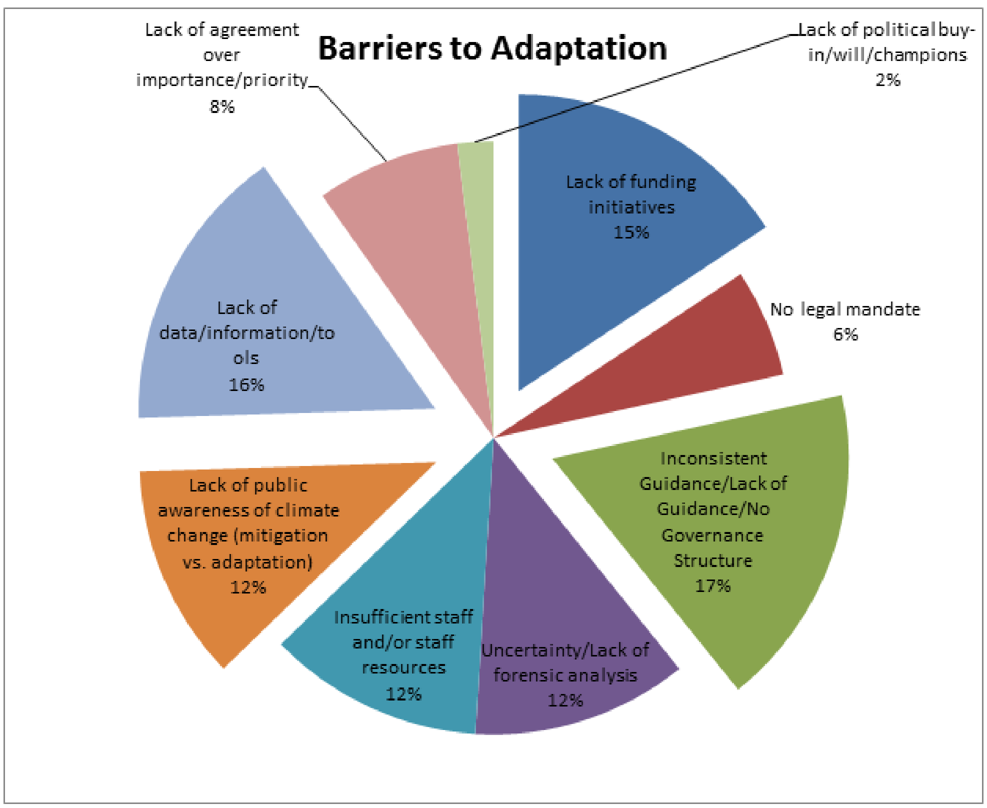
The design failure related to the pumps' junction boxes and the electrical control room being below the hydraulic grade which caused the electrical failure (Bousquet, 2009). According to TD Economics, by 2050, costs related to infrastructure losses, health system costs, reduced business productivity and lost hours will be 4 to 9 times higher than in 2020; somewhere between $21 billion and $43 billion a year. TD concluded that investments in infrastructure must be made to protect them, in order to adapt them to the risks of natural disasters. Each dollar invested represents a gain of $9 to $38 in damages avoided (Fillion, 2014).

Additional tables in Appendix B provide further discussion on adaptation measures including knowledge and tools, policies, best practices, actions, innovation, and actions of communities of practice (i.e. engineers, planners, etc.) to reduce risks associated with various climatic phenomena.

## 4.4 Barriers and Gaps

A review of literature and outcomes from the interviews with subject matter experts conducted for the State of Play report, identified notable gaps in knowledge or capacity and barriers to climate change adaptation. These barriers to adaptation have been generalized and illustrated in Figure 4-2. Examples of barriers associated with various levels of government and other groups have been summarized in the following report sections by level of Government and also based on the private realm. It should also be noted that some of the noted barriers may also be linked or shared between various governments and/or organizations.

**Figure 4-2 Barriers to Adaptation**



### 4.4.1 Federal Government

- Lack of available funding, time and staff resources for both development of strategies and implementation through infrastructure investment (Bishop, 2015). Funding is needed to assess flood risks, update flood maps and models with current tools, implement infrastructure upgrades, and develop climate change adaptation plans (Moghal & Peddle, 2016).
- Prescriptive guidance and regulations are preventing locally-based adaptation (i.e. Hurricane Hazel may produce a smaller floodplain than a Short Duration High Intensity (SDHI) event, lack of flexibility in guidelines to make locally informed decisions, guideline updates take too long for adaptive management.)
- Construction codes have not historically accounted for key stormwater related challenges, including increased building footprint size, which increases impervious cover in urban areas. In the absence of construction code requirements, it is unclear to many decision makers how building footprint size issues that affect stormwater runoff should be addressed, resulting in municipal liability for increasing stormwater runoff production.
    - It is acknowledged that the construction code review(s) currently underway may address several of the aforementioned issues; however, appropriate resources and evidence is required to warrant code changes, including standards and cost-benefit information.
    - National Model Construction Codes and provincial construction codes have historically impeded the adoption of measures that serve to reduce the risk of damage to structures/ infrastructure during some types of extreme events. For example, many building construction and design factors that could serve to limit urban/basement flood and wildland fire risk have not historically been incorporated into codes. Limited uptake of certain key measures may also result from interpretation of code wording by local authorities, resulting in inconsistent protection of buildings and communities across Canada.

**Table 14: Interpretation of article 2.4.6.4. of the NPC**

| | Province or Region | | | | | |
|---|---|---|---|---|---|---|
| Response | BC[1] | AB[2] | SK[3] | MB[4] | ON[5] | NB/NS[6] |
| All new homes | 7% | 52% | 43% | 52% | 14% | 29% |
| Most new homes | 12% | 29% | 43% | 20% | 12% | 29% |
| Rare, specific circumstances | 66% | 19% | – | 28% | 60% | 14% |
| Code does not require BWVs in any circumstance | 7% | – | – | – | 3% | – |
| Not sure how this part of the code would be interpreted in my municipality | 2% | – | – | – | 3% | – |
| No response | 6% | – | 14% | – | 8% | 28% |

[1] n=41, [2] n=21, [3] n=7, [4] n=25, [5] n=58, [6] n=7

A study was completed by the Institute for Catastrophic Loss Reduction in 2013 that conducted a national survey of local code authorities and officials on the interpretation of the National Plumbing Code (NPC). The intention was to understand the discrepancies in the interpretation of Article 2.4.6.3 of the 2010 NPC as it related to protection of buildings from storm and sanitary sewer backflow. At the time the article was adopted outright in many provincial plumbing or building codes. For example, Table 14, from the report, shows the varying responses for Sentence 2.4.6.4(3) on Protection from Backflow and the results clearly demonstrate how the same code can be interpreted differently as a result of code wording (Sandink, 2013).

- Standards such as the Ontario Drinking Water Quality Management Standard (DWQMS) offer municipalities a way to reduce liability associated with regulatory non-compliance and support continual improvement within municipal operations. Unfortunately, no such standards exist for wastewater or stormwater and no current direction is provided to municipalities as to how climate change is to be considered as part of the risk assessment component of a Quality Management Standard.
- Regulations, such as the Ontario Development Charges Act, are impeding municipalities from making science-based decisions.
- Recent and ongoing studies have identified needs that could represent barriers to facilitating adaptation in the water resource management sector in Canada. These include further defining jurisdictional roles and responsibilities, providing for more integrated management among jurisdictions, enhancing adaptive capacity through existing institutional frameworks (e.g., water licensing systems), improving understanding of local water systems and users, fostering local partnerships and establishing transparent institutional arrangements at all levels. For example, considering jurisdictional roles alone, at least three federal agencies, three provincial agencies, Conservation Authorities and municipalities all play significant roles in water shortage management in Ontario. The recent development of a provincial drought response plan in Ontario has helped to clarify local responsibilities for drought management, which improves the capacity of communities to address water-shortage issues. In Alberta, the 2001 *Water Sharing Agreement* was promulgated to enhance adaptive capacity by instituting an effective means of conserving water and distributing it equitably on a large scale (Environment Canada, 2006).This barrier is also noted as a Provincial Government issue.
- Complicated, long and onerous process to apply for program funding (Moghal & Peddle, 2016). This barrier is also noted as a Provincial Government issue.
- Given the existing amount of climate change information and data, but limited direction and standards on how to use the information, municipalities are collaborating to support development of a one-window portal such as the Prairie Climate Centre (PCC).

### 4.4.2 Provincial Government

- The stormwater infrastructure design criteria for major and minor systems are out of date in some jurisdictions, and they typically do not incorporate the effects of climate change.
- There are no stormwater regulations or regular reporting requirements in comparison to drinking water. As a result, there are varying levels of service within an urban area depending upon the age of development and little political will to fund maintenance and operation of stormwater management practices. In Lake Simcoe, Ontario a study found that out of the 98 stormwater management ponds surveyed, 47 ponds did not meet provincial permits and required clean out. To bring the 47 stormwater ponds back to their design efficiency, the total maintenance cost was estimated at approximately $18 million (LSRCA, 2011).
- There is a lack of provincial direction as to how municipalities are to define an acceptable level of service for stormwater management particularly within older urban areas. This creates inconsistencies in the way municipalities manage risk and exposes them to liability from extreme weather events.
- Traditional guidelines for stormwater are based on the performance of a practice, which does

not address receiving stream requirements. Therefore, service requirements associated with other infrastructure (water, wastewater, and watershed) are not being addressed.

- Many stormwater guidelines have not been updated to reflect new technologies or science. New development is being designed with outdated technologies and standards with little opportunity for municipalities to require development industries to incorporate low impact development (LID) / green infrastructure.
- Much of the responsibility for climate change adaptation falls to municipal governments. Provincial governments have struggled to provide strong climate change policies to support municipalities. There is a gap in leadership in provincial and federal governments (Bishop, 2015).
- Lack of institutional and financial capacity to enforce, update and invest in climate change adaptation actions (Moghal & Peddle, 2016).
- Lack of flexible funding for climate change adaptation measures such as incorporating stormwater controls within road capital projects to build flood resiliency. For example, the City of Mississauga incorporated GI into a recent road reconstruction. Monitoring of the site found that the GI practice was able to reduce stormwater volume of a 100 year event by 30%, dramatically reducing the strain on the existing aging infrastructure. If transportation funding could include stormwater retrofits (adding approximately 10% to the total costs) this could be an efficient and feasible option to build resiliency into existing urban areas as land acquisition is not required. The City of Mississauga has almost 2,000 km of roadways and incorporating green infrastructure into 20-30% of roadways would provide improved climate change resiliency.
- Infrastructure funding programs such as the Ontario Community Infrastructure Fund (OCIF) and the Small Communities Fund (SCF) are found to have complicated, long and onerous processes to apply for program funding (Moghal & Peddle, 2016).
- Currently, funding models include provincial and federal assistance for capital works but not operation and maintenance, as mentioned above. Studies have found municipalities lack proper dedicated funding for maintenance of stormwater practices.
- There is lack of official guidance on risk assessment. Municipalities innovate by working with other organizations and academia to create local risk assessment processes. Conservation Ontario's *Business Case for Strategic Reinvestment* advocates the urgent need to address gaps in floodplain management programs, flood operations and aging infrastructure, by adequately funding, staffing and providing Conservation Authorities with the tools to meet their responsibilities (Conservation Ontario, 2013).

### 4.4.3 Municipal Government

- Lack of understanding to perform vulnerability assessments, implement adaptation plans and shovel-ready actions. Municipalities fear that knowing infrastructure risks and liabilities, but lacking financial resources to invest in upgrades, increases the potential for litigation.
- While there are tools for identifying risk and vulnerability, there are no tools to assist municipalities with development of adaptation strategies. Specifically, there is little

understanding of how specific adaptation measures will reduce risk and what the return on investment is for implementing a measure in light of more extremes.

- There is no standard forensic accounting procedure/approach for evaluating direct and indirect costs of an extreme event (i.e. current forensic accounting of an event identifies costs for clean-up but rarely identifies long term financial impacts to health or asset life). A consistent approach to analyzing the impact of an extreme event would be helpful in building the business case for investment in adaptation.
- Municipal governments own and operate almost 60% of the public infrastructure in Canada. They are struggling to maintain this infrastructure, in part because the rate of increase in municipal revenues has not kept up with Canada's growth rate (FCM et al, 2016, Carlton, 2012). Property tax is the primary source of municipal revenues and is not an adequate revenue base to service infrastructure needs (Carlton, 2012). Infrastructure programming over the past few years has been mostly short-term and unpredictable and does not adequately address Canada's infrastructure needs (Carlton, 2012). Asset failure, loss of service and insurance claims due to extreme weather are costly and the financial liability is potentially substantial. The example in Figure 4-3 illustrates the costs associated with the August 2005 storm that caused flooding across Toronto (e.g., insurance claims mostly for personal property). The cost to replace the failed Finch Avenue culvert was less than 1% of the total costs associated with event. The Insurance Bureau of Canada estimates losses and loss adjustment expenses to be $740 million in 2015 dollars (IBC, 2016).

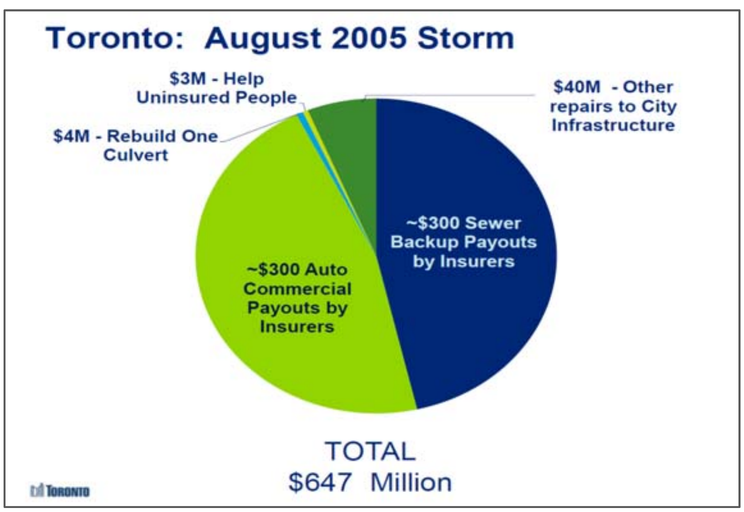



**Figure 4-3 Failure of Finch Avenue in Toronto – Damages** (Source: City of Toronto, 2013)

- For municipal and regional governments, there is lack of coordination and leadership to connect different municipalities with shared watersheds, lake/coastlines, interests (Bishop, 2015).
- Lack of political and staff understanding as to how climate change may impact municipal services (Bishop, 2015). For example, a survey of British Columbia Environment Ministry employees found 49% of survey respondents are not clear on how climate change will affect their work (BC Stats, 2012).
- Lack of political and developer will to implement new technology (Moghal & Peddle, 2016).

- Municipalities are still in the phase of comparing cost and benefits of action versus no-action scenarios.
- Climate change adaptation projects are often competing with other projects with more public and political will (Bishop, 2015).
- Inconsistencies with climate change data and data interpretation between municipalities (Bishop, 2015).
- Communicating the need for climate change adaptation to local officials and obtaining federal government commitment to address local adaptation challenges (Carmin et al., 2012).
- Lack of funding resources as municipalities receive some funding for capital work projects (typically 1/3 split between, municipal, provincial, federal government). There is currently limited funding to support maintenance and enforcement.
- In highly urbanized municipalities, there is not enough municipally owned land that can be used to implement source controls such as low impact development and/or green infrastructure.
- Lack of municipal staff and resources dedicated to emergency response during extreme events. For example, flood response is mainly provided by fire departments and road works staff. Flooded roadways can cause their vehicles to stall, preventing workers from accessing critical infrastructure.

### 4.4.4 Customers and Citizens

- Lack of communication strategies and programs to inform the public that there is a need for immediate action to better understand climate change (Bishop, 2015).
- Lack of flood risk awareness. There is need to encourage behavioural changes and increase uptake of residential incentive programs to reduce flood risk (Moghal & Peddle, 2016).
- Urban/basement flood reduction programs implemented on private property (e.g., backwater valve, foundation drain disconnection, clean-out capping, etc.) face significant barriers and homeowners are often not complicit. Flood protection measure maintenance is most likely not completed by property/homeowners. When properties are sold, information on flood protection measures and maintenance requirements is likely not passed on to new owners.

### 4.4.5 Social Component

This section presents the barriers and the associated knowledge gaps that hinder adaptation measures to social vulnerabilities of at risk populations and emergency management services.

- Extreme events such as tornadoes pose technological challenges. Short timeframes for detection and warning allow less time for individuals to prepare and seek shelter. This is why loss of property and life is higher with tornados than with other types of disasters (Greenough et al, 2001). Similarly, with increased short duration and high intensity rainfall events, there is little to no time for warnings. This can result in loss of life, failure of infrastructure and damage to property.

- Resources available for disaster mitigation may be shared with those for a variety of public health issues (McMichael et al, 2003).
- Deliberations over the distribution of costs for adaptation measures between public and private agencies can be a significant barrier to action (Health Canada, 2008).
- Any potential return on investments to mitigate natural hazards is realized only after a disaster is averted, whereas the investment costs are immediate and potentially significant (Health Canada, 2008).
- There is limited knowledge and understanding of health risks associated with specific natural hazards. For example, in the aftermath of flooding, citizens can be exposed to mould for a prolonged period of time. The characteristics and/or qualities that make certain populations more vulnerable and the distribution of such groups within Canada are important to understand in order that appropriate action is taken (Health Canada, 2008).
- Indicators are not well defined and there is limited data on social, psychological and mental health impacts (Health Canada, 2008).
- There is limited guidance and training on the role of health services in mitigating natural hazards and aiding victims of natural disasters (Health Canada, 2008).
- There are no effective warning and prevention systems for natural hazards, like floods, that occur frequently and quickly (Health Canada, 2008).
- There are no measures in place to evaluate outreach strategies for changing individual behaviors to reduce health risks (Health Canada, 2008).

# 5.0 Increased Engagement of Climate Change Adaptation in Canada

## 5.1 What is Adaptation?

Adaptation to climate change is any activity that reduces the negative impacts of climate change and/or activities that take advantage of new opportunities that may arise (EU, 2017; Lemmen et al, 2008). Adaptation can include activities that are planned to address anticipated impacts or react after impacts have occurred. It has been shown that well planned, early adaptation actions have the potential to save money and lives in the future (EU, 2017).

Adaptation will usually not take place in response to climate change alone, but in consideration of a range of factors with the potential for both synergies and conflicts (Lemmen et al, 2008). While taking action does not preclude the possibility of future negative impacts, effective adaptation should lessen the magnitude of future impacts. Understanding the level and underlying causes of vulnerability also contributes to better, more informed decision-making and policy development by providing a basis for establishing priorities.

## 5.2 Overview

This section summarizes the current state of adaptation in Canada, based on subject expert interviews and literature review. The study team reviewed the results from the National Municipal Adaptation Survey (UBC, 2014) completed in 2012 which polled 481 municipalities from across Canada with populations ranging from less than 5000 to greater than 1 million. The respondents reported damages from flooding, stormwater discharges and heavy snowfalls as their top risks to climate change. With a changing climate, respondents are expecting their vulnerabilities to increase with higher than average rainfall and/or snowfall resulting in more flooding and drought periods. For adaptation planning, the survey demonstrated that, “45% of the respondents do not have an adaptation plan/strategy and are not considering adaptation planning at this time” and only 20% identified that “we are beginning to discuss adaptation, but are not at the stage of developing a plan or strategy, or incorporating adaptation into an existing plan”. Despite the acknowledgment of increasing vulnerabilities of municipal infrastructure to climate change impacts and the increasing risk to urban, riverine flooding and other failures, there seems to be little work being done in adaptation.

Feltmate and Thistlewaite (2012) documented the opinions of approximately 80 leaders from across Canada representing industry, finance, law, academia, aboriginal communities, government, youth and NGOs through the Climate Change Adaptation Project: Canada (CCAP). This project was designed to identify practical, meaningful and cost-effective adaptation solutions to the most challenging impacts of climate change facing Canada. The CCAP highlighted a number of priority areas as outlined in Figure 5-1.

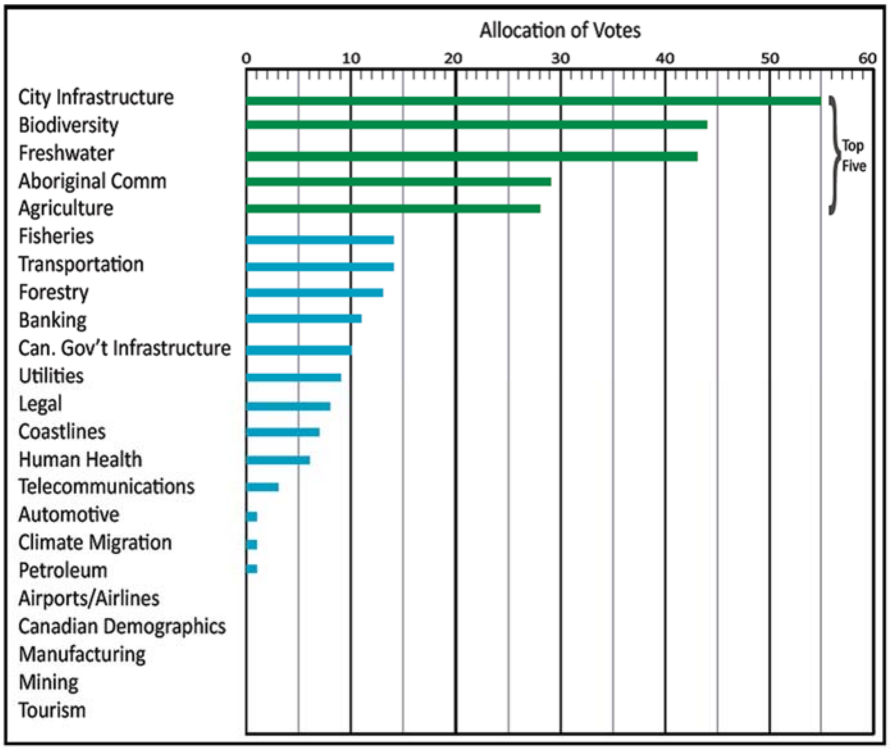



**Figure 5-1 Prioritization of Climate Change Adaptation Sectors for Canada as developed for the Climate Change Adaptation Project: Canada**

Source: Feltmate and Thistlewaite (2012)

To address some of these challenges, the federal, provincial and municipal governments have partnered to develop the Pan-Canadian Framework on Clean Growth and Climate Change which outlines new actions for building resilience through infrastructure. These include investing in infrastructure to build climate-resilience and developing climate resilient codes and standards (Government of Canada, 2016c).The Pan-Canadian Framework[26], released in December 2016, outlines critical actions that Canada will take to grow the economy while reducing GHG emissions. There is also recognition in the Framework that Canada must take action to adapt to the changing climate and to build climate resilience, specifically recognizing unique climate change issues facing coastal, northern and Indigenous communities. However, the language associated with adaptation actions is much less definitive than the language associated with GHG reduction/climate change mitigation actions.

### 5.2.1 Awareness, Engagement and Collaboration

Municipalities who have experienced extreme events in the past decade, including flash flooding, urban flooding, riverine flooding, wildfires and ice storms, are aware of their vulnerability to climate change. However, municipalities that have not experienced an extreme event, or have limited resources may not be aware of the impacts of climate change. It is hoped that this State of Play report will provide the basis of the information from which municipalities can begin the

[26]Abstracted from Government of Canada, 2016c and 2016d.

conversation and garner political support to properly assess the risks and identify vulnerabilities within their community regardless of whether they have experienced an extreme event or not.

Despite limited guidance and direction from provincial and federal governments, municipalities are making efforts to adapt to climate change. Municipalities are collaborating internally and externally to provide consistent warning messages to public health units which are then used by public and emergency services to coordinate an appropriate response to extreme events. This approach was implemented by Toronto Public Health through the pilot, Provincial Harmonized Heat Alert and Response System (HARS).

Given the wealth of climate change information and data, but limited direction and standards on how to use the information, prairie provinces and academia organizations are collaborating to develop a one-window portal such as the Prairie Climate Centre[27] (PCC). The PCC is a collaboration of the University of Winnipeg and the International Institute for Sustainable Development (IISD). The PCC enables governments, businesses and community members across the Prairies to reduce their vulnerability to climate change by providing access to an innovative, stakeholder-driven hub for data, guidance, research, knowledge exchange, training and capacity building (PCC, 2016). Other similar centres include Ouranos[28], the Pacific Climate Impacts Consortium[29] (PCIC), the Ontario Centre for Climate Impacts and Adaptation Resources[30] (OCCIAR), and the Atlantic Climate Adaptation Solutions (ACASA) Project[31].

It is important to broaden the scope of stakeholders involved in such regional centers. While the public is generally aware of climate change, more engagement is needed to raise awareness about the impacts of climate change, the need for adaptation measures to reduce risks and improve household-level adaptation. For example, the 2017 RBC Canada Water Attitudes Survey found that 67% of Canadians expected that climate change will negatively affect water resources (RBC, 2017). In contrast, a recent survey in the GTA found that 44% of respondents had experienced flooding, but only 9% expected they would be affected again in the future and few had adopted appropriate flood risk reduction measures (Freeman Associates, 2016).

### 5.2.2 Assessment of Risks, Vulnerabilities and Opportunities

Risks to critical infrastructure are becoming more and more interdependent as the economic, technological, and social processes of globalization intensify. The ability to evaluate interdependent vulnerabilities remains difficult. In a local context, municipalities are making an effort to perform infrastructure risk assessments using a wide range of tools as there is limited guidance or standards on which tools to use. The most commonly used tools include Engineers Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol tool, International Council for Local Environmental Initiatives (ICLEI) Building Adaptive & Resilient Communities (BARC) tool, and the Australian and New Zealand risk management frameworks (AS/NZS 4360).

[27] http://prairieclimatecentre.ca/
[28] https://www.ouranos.ca/en/
[29] https://pacificclimate.org/
[30] http://www.climateontario.ca/
[31] https://atlanticadaptation.ca/en/home

These tools assist municipalities in identifying their vulnerable areas and prioritizing capital infrastructure works and upgrades. Even so, some infrastructure sectors are finding that these tools do not adequately address their specific needs and have developed their own tools. A review of the outcomes from vulnerability assessments completed using the PIEVC Engineering Protocol indicated that completion of vulnerability assessments led to enhanced awareness within organizations of climate change issues, particularly at the senior management level (AECOM, 2016). Funding, however, has been identified as the greatest barrier to the implementation of adaptation actions and recommendations of the risk assessment. Many municipalities are exploring various funding avenues including the introduction of stormwater rates (i.e. Mississauga, Richmond Hill, London - Ontario) or increasing water rates altogether (Toronto increased water rates more than a 100% since about 2004). There is need for dedicated provincial and federal funding towards specific adaptation actions. One example is the Clean Water and Wastewater Fund (CWWF) which has dedicated $62 million to the Ottawa Combined Sewage Tunnel to reduce CSOs to the Ottawa River.

While predictive climate change modelling technology is currently advancing, gaps remain in understanding the full financial implication of extreme events, determining an acceptable level of service, and quantifying how adaptation measures reduce risk. To address these gaps, Credit Valley Conservation (CVC) has been awarded funding by the National Disaster Mitigation Program (NDMP) to develop a Municipal Risk and Return-on-Investment Tool to assist municipalities to make science-based cost-effective decisions on prioritizing water infrastructure investments to improve the socio-economic conditions of vulnerable communities and protect the environment for the future. Starting in spring of 2017, CVC will develop the Tool to quantify the risks and costs associated with flooding events, with consideration of future climate change. The Tool will also incorporate a more comprehensive list of costs than is typically considered for extreme rainfall, incorporating the impact of vulnerable populations on overall risk and costs. The Tool will allow municipalities to prioritize infrastructure investment based on the current state of infrastructure, the environment, and community needs. The output from the tool will be enumeration of the risk reduction and return on investment achieved by a variety of adaptation measures (e.g., traditional infrastructure, green infrastructure, land use planning, emergency management and community outreach), which can then be used to make sound decisions for selection and investment of those measures.

### 5.2.3 Adaptation Planning and Actions

Various organizations on local and provincial levels are initiating, or looking to initiate, adaptation actions to address climate change. One example is local municipalities working with public health units to better inform their emergency management plans under extreme weather.

On a federal level, Standards Council of Canada is working on a number of initiatives to update standards and/or introduce new standards to simplify climate change adaptation for provincial and municipal governments. These initiatives include standardization of weather data, climate information and climate change projections, update of existing infrastructure standards including those references in the NBCC and new standards for Northern infrastructure. As outlined in Appendix B, there are provincial climate change strategies, adaptation plans and action plans. Section 5.3 provides a number of examples that present implementation efforts from various levels of government. The federal government has also introduced the $3.4 billion Public Transit

Infrastructure Fund (PTIF) and the $2 billion Clean Water Wastewater Fund (CWWF) to encourage economic growth and support sustainable, livable communities (Minister of Infrastructure and Communities, 2016).

On a provincial level, Ontario and Canada are working towards the development of a Domestic Action Plan for Lake Erie to address excess nutrients and algal blooms. The Province of Ontario is also updating their stormwater management guidelines to include low impact development/ green infrastructure measures. The Province of Newfoundland and Labrador has developed a variety of climate change datasets for all areas of the province that can be used for adaptation planning and infrastructure design.

On the municipal level, Federation of Canadian Municipalities (FCM) is making efforts to address climate change and strengthen infrastructure planning through investments in sustainable infrastructure. FCM launched two new programs, the Municipalities for Climate Innovation Program and the Municipal Asset Management Program. These programs will provide municipalities with access to funding, training and learning opportunities to increase their capacity to reduce greenhouse gas emissions, build resilience to the impacts of climate change, and support better planning and management of municipal infrastructure (FCM, 2017). These initiatives will help address a number of keys gaps identified in this report related to funding and professional training capacity. As part of the Great Lakes Climate Change Adaptation Project, International Council of Local Environmental Initiatives (ICLEI) has engaged twenty (20) Ontario municipalities to complete Climate Change Risk and Vulnerability Assessments and develop local adaptation plans into implementation-ready actions. Furthermore, local municipalities such as the City of Toronto are endorsing increased inspection and maintenance to enhance their infrastructure systems (i.e. culverts to ensure capacity during extreme rainfall events).

### 5.2.4 Measurement of Success and Reporting

The Adaptation Platform Measuring Progress Working Group completed a study, in 2015, on applying sustainability indicators to measure progress on adaptation. The study applies sustainability indicators to four sectors including coastal management, flood management, infrastructure and health and the report discusses the context around the indicators, limitations and potential data sources for each. The working group will also be addressing another barrier/knowledge gap on how-to measure progress and success of adaptation.

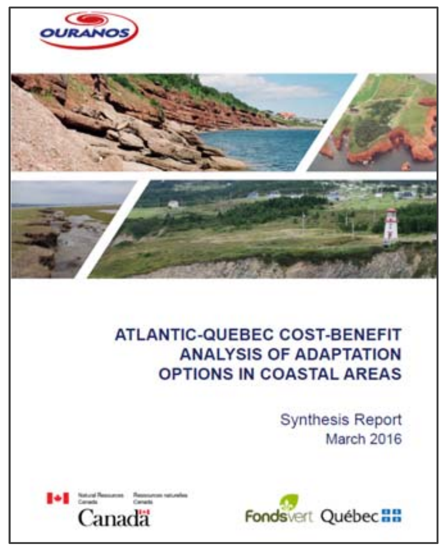
## 5.3 Success Stories and Positive Steps

The examples that follow provide specific evidence of successful adaptation actions with regard to infrastructure and buildings across Canada. This list is not meant to be exhaustive but simply to highlight some of the work from across Canada advancing climate change adaptation.

Additional case studies are also presented in Appendix C to highlight Canadian communities and organizations actively engaged in climate change adaptation.

**National Principles, Best Practices and Guidelines – Flood Mapping**: Natural Resources Canada and AECOM developed updated guidelines to supplement the Hydrologic and Hydraulic Procedures for Floodplain Delineation and its Addendum that were, respectively, published in 1976 and 1980 under the Flood Damage Reduction Program. These guidelines include recent advancements in science and technology, regional best practices and international guidelines and best practices. The updated guideline provides an overview of the flood mapping framework and key principles of effective risk management, a detailed review of national, regional (provincial and territorial), and international best practices in flood mapping as well as the technical guidelines that inform decision makers in the establishment of local flood mapping programs and the procurement of flood mapping.

https://www.cwra.org/images/pdf/National_Principles_Best_Practices_and_Guidelines_--_Flood_Mapping_Final_Deliverable.pdf




**Developing Tools to Support Adaptation Planning and Action:** The Economics Working Group of Canada's Climate Change Adaptation Platform, supported by Natural Resources Canada, launched a program that aimed to create economic knowledge and tools to help decision-makers in Canada's private and public sectors make better adaptation investment choices and policy decisions. Under this program, the research project Economic Assessment of the Impacts of Climate Change and Cost Benefit Analysis of Adaptation Options, targeted Quebec's coastal areas and the Atlantic Provinces. While climate change and its impacts have been studied for some time, research to analyze the vulnerability of communities and infrastructure to such impacts, identify suitable adaptation options, and estimate damages potentially resulting from climate change has only recently begun in Eastern Canada. The main objective of the project has been to determine the economic viability of various adaptation options in protecting the coastline thereby supporting effective planning (Ouranos, 2016).


**Transport Canada's Northern Transportation Adaptation Initiative (NTAI)[32]:** One of the projects supported through the NTAI is the initiative that provided the Government of Nunavut with funding support to better understand the permafrost conditions beneath the Iqaluit airport. As a result of climate change, the Iqaluit airport's runway is becoming more susceptible to permafrost thaw, increasing the likelihood of settlements, sinkholes and other instabilities that can affect the safety of the runway. By studying

[32] Photo credit: http://static.progressivemediagroup.com/uploads/imagelibrary/Iqaluit%20International%20Airport.jpg

these issues and assessing the current state of permafrost at the airport, the Iqaluit airport authority was able to identify specific locations at the airport that are at risk of increased damage from climate change and incorporate recommendations for adaptive techniques into the design of the larger rehabilitation project.

**Review of building codes and standards:** The SCC supports and complements NRC in this regard. The following quote from page 21 of the final report of the working group on Adaptation and Resilience under the Pan-Canadian Framework provides context for this collaboration: "Work is already underway to incorporate climate considerations into codes and standards. The federal government's 2016 Budget included funding for initiating and advancing these efforts over the next five years. This work will include the development of a revised national building code by 2020 (residential, institutional, commercial and industrial buildings). Guides that integrate climate resilience into the design and rehabilitation of public infrastructure (e.g., bridges, roads, potable water, and wastewater systems) are also being developed. Additional codes and standards related to climate resilience could be developed or updated to address areas, such as natural infrastructure, emerging technologies, renovations to existing building stock, specific complex building types like health care facilities, and environmental impact assessments. Work on codes and standards should also consider how they would be meaningfully implemented in Indigenous communities and other communities with limited enforcement capacity" (WGACR, 2016).

**New Standards:** As Canada's national standardization body, SCC develops solutions and strategies that leverage the existing Canadian standardization infrastructure and contribute to protecting the health and safety of Canadians, as well as the sustainability of Canada's development and economy. Through its standardization network of experts, SCC has the expertise to identify standards development solutions that reflect the unique circumstances of Canada's North.

Standards for design, construction, maintenance and decommissioning are all important to the infrastructure life cycle. They specify performance and material requirements that can be used as the integration point for climate-related risks into infrastructure planning and development processes. Standards incorporate assumptions and directives regarding climate and weather conditions (such as temperature, precipitation and wind) and climate-related events (for example, flooding and freeze-thaw cycles) that infrastructure must withstand.

From 2011-2016, SCC led Phase 1 of the Northern Infrastructure Standardization Initiative (NISI) with support from Indigenous and Northern Affairs Canada (INAC). NISI was designed to address and work with the unique circumstances found in Canada's North. The key to success was the establishment of the Northern Advisory Committee (NAC). The NAC was established to provide strategic advice, input and guidance for the initiative to ensure that deliverables were relevant in a northern context and in the best interest of northerners. Under NISI, five new National Standards of Canada (NSC) were developed for northern infrastructure, including:

- CAN/CSA-S500-14 - *Thermosyphon foundations for buildings in permafrost regions*
- CAN/CSA-S501-14 - *Moderating the effects of permafrost degradation on existing building foundations*
- CAN/CSA-S502-14 - *Managing changing snow load risks for buildings in Canada's North*
- CAN/CSA-S503-15 - *Community drainage system planning, design, and maintenance in northern communities*
- (In Development) CAN/BNQ 2501-500 - *Geotechnical Site Investigations for Building Foundations in Permafrost* (completion pending for 2017)

To build adaptation capacity within northern communities, SCC also facilitated the development of a variety of training and communication materials to provide end users with different methods to learn and apply the content of the standards.

## Provincial Standards, Guidelines and Policies

**Requirements for Consideration of Climate Change:** The Province of British Columbia Ministry of Transportation and Infrastructure's technical circular established the requirement for all of the Ministry's design to consider future climate projections, incorporate appropriate adaptation measures where feasible, and document the process and findings (BC Ministry of Transportation and Infrastructure, 2016).The *Living Water Smart* strategy outlines new approaches to water management that "will address the impacts from a changing water cycle, increased drought risk and other impacts on water caused by climate change." It also links climate change considerations to provincial funding and looks to introduce higher provincial flood standards. The *New Water Sustainability Act* allows the government to manage surface water and groundwater as one resource and allows water licenses to be reviewed and amended in light of climate change.

The Province of Newfoundland and Labrador commissioned a Climate Projections Study in 2013 that identifies how the province's climate is projected to change by mid-century. This study includes temperature projections for sixteen (16) locations across the province. Specifically, daily mean, minimum and maximum temperatures are available for all seasons. Projections are available for technical concepts, such as heating degree-days, cooling degree-days, growing degree days, frost days and heat waves. The study also developed future precipitation projections for the sites. Specifically, daily mean precipitation, daily precipitation intensity, and precipitation totals for three, five and ten-day periods are provided for all seasons, as well as projections for dry spells. See http://www.turnbackthetide.ca/tools-and-resources/climate-data-and-tools.shtml

The Province of Ontario, in the Provincial Policy Statement 2014 (Ontario, 2014), issued under the Planning Act, directed that "Infrastructure, electricity generation facilities and transmission and distribution systems, and public service facilities shall be provided in a coordinated, efficient and cost-effective manner that considers impacts from climate change while accommodating projected needs". As well, the "Planning authorities shall consider the potential impacts of climate change that may increase the risk associated with natural hazards."

Another Ontario based initiative is the *Infrastructure for Jobs and Prosperity Act,* which directs that infrastructure be designed to be resilient to the effects of climate change. Ontario's provincial adaptation plan, *Climate Ready: Ontario's Adaptation Strategy and Action Plan, 2011-2014* outlines five (5) broad goals and more than thirty (30) actions including: amending the Ontario Building Code, completing infrastructure vulnerability assessments and creating climate projections throughout the province. The 2016 mandate letter to the Ontario Minister of Environment and Climate Change includes direction to ensure climate change adaptation is taken into account in government decision-making including adaptation considerations for public infrastructure investments and government procurement decisions. The mandate letter also directs development of a Climate Change Adaptation Plan that sets out priorities and actions Ontario will take to adapt to the effects of climate change. While all of these actions are a step in the right direction, recognition of climate change in infrastructure design in Ontario is still not widespread with detractors' citing lack of direction from the Province on how to specifically address climate change.

**Ontario Ministry of Transportation – Vulnerability Assessment:** The MTO[33] has undertaken a resiliency assessment of provincial highway drainage infrastructure to determine the potential excess capacity that may exist within the current infrastructure in light of increasing rainfall events. An investigation into the possible magnitude of changes in rainfall predictions using available tools and climate change modeling studies provides the most current and relevant hydrologic data. The study provides a basis for identifying the effectiveness of current drainage designs standards and procedures for the future lifecycle of drainage infrastructure, storm sewers, culverts and bridges. It also provides some adaptation strategies to address climate change impacts on the provincial highway network over the range of design service life for the different components of the highway infrastructure managed by MTO. The review has shown a strong resilience through excess capacity.

**Understanding Increasing Risk from Extreme Events[34]:** The New Brunswick government's approach to known and increasing ice jam flood risk in Perth-Andover-Tobique in 2013, is illustrative. The provincial government and the local communities implemented a suite of measures to prevent or mitigate the risk of similar events in the future. Measures included investments in ice jam modeling and prediction, improved warning systems, flood barriers, flood proofing, relocations and land use restrictions. The measures were based on

[33] Report available via URL https://www.library.mto.gov.on.ca/SydneyPLUS/Sydney/ViewRecord.aspx?template=Books&record=6f913c0a-52ff-4afe-9587-e118d6325a9e&lang=en-US
[34] Photo Credit: https://awd1970.files.wordpress.com/2015/04/cc9ttdlumaajajj.jpg

a science-based study of the root causes, event probabilities, and evidence and value-based decisions. As a result the government invested $13 million in various measures with the understanding that measures would likely pay for themselves in 15 years.

**Confederation Bridge[35] between New Brunswick and Prince Edward Island:** One positive example of adaptation is the Confederation Bridge, which was built one (1) metre higher than required to accommodate sea level rise over its one hundred year design lifespan.


**British Columbia work on Sea Level Rise[36]** (abstracted from Ausenco Sandwell, 2011)**:** In 2011, the Province of British Columbia (BC) commissioned advice on how to update its existing guidance for coastal exposure in British Columbia to include consideration of rising sea levels. Those guidelines (Government of British Columbia, 2004) assumed static sea levels and did not account for climate change. New guidelines, which amend the 2004 guidelines, incorporate projected future sea level rise into the determination of setbacks and flood construction levels for coastal developments. These guidelines are intended to help local governments, land-use managers and approving officers to implement land-use management plans and make development approval decisions for lands exposed to coastal flooding hazards and sea level rise.

**<u>Watershed and Multi-jurisdictional Studies</u>**

**Credit Valley Conservation, City of Mississauga, Region of Peel, Town of Caledon, and City of Brampton - Integrated Watershed Infrastructure Risk Assessment in light of Climate Change:** As showcased in the examples in Section 3.2, urban and natural environments are complex. A vulnerability to one component may impact other components, increasing the risks and their associated costs for communities. Furthermore, implementing adaptation measures without understanding linkages may have unintended consequences. Recognizing these interdependencies, the Region of Peel, City of Mississauga and Credit Valley Conservation underwent a watershed-scale study using PIEVC, and watershed and lake modeling to identify linkages, risks and adaptation measures Partners from planning, EMS, public health,

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[35] Photo Credit Confederation Bridge http://www.confederationbridge.com/gallery/gallery1/3.jpg

[36] Photo Credit Sea Level Rise
http://www.industrytap.com/is-your-city-destined-to-be-washed-away-by-global-sea-rise/17025/sealevel

transportation, drinking water, wastewater stormwater, fisheries and surface and Lake Ontario experts were consulted to build a watershed-level understanding of implementation measures (CVC et al, 2014).

The Study found that when applying a traditional approach, (looking only at stormwater infrastructure assets) adaptation measures were limited to capital investments (ref. Figure 5-2). When examining the linkages between types of infrastructure, the environment and social vulnerabilities, a different set of capital works priorities emerged which better addressed reducing community risks to extreme events (ref. Figure 5-2). The Study found that where stormwater measures alone may be insufficient, these areas may inform land-use planning (particularly infill and redevelopment areas), land acquisition for parkland dedication or priority areas for emergency planning and outreach. For further information please refer to Appendix C.

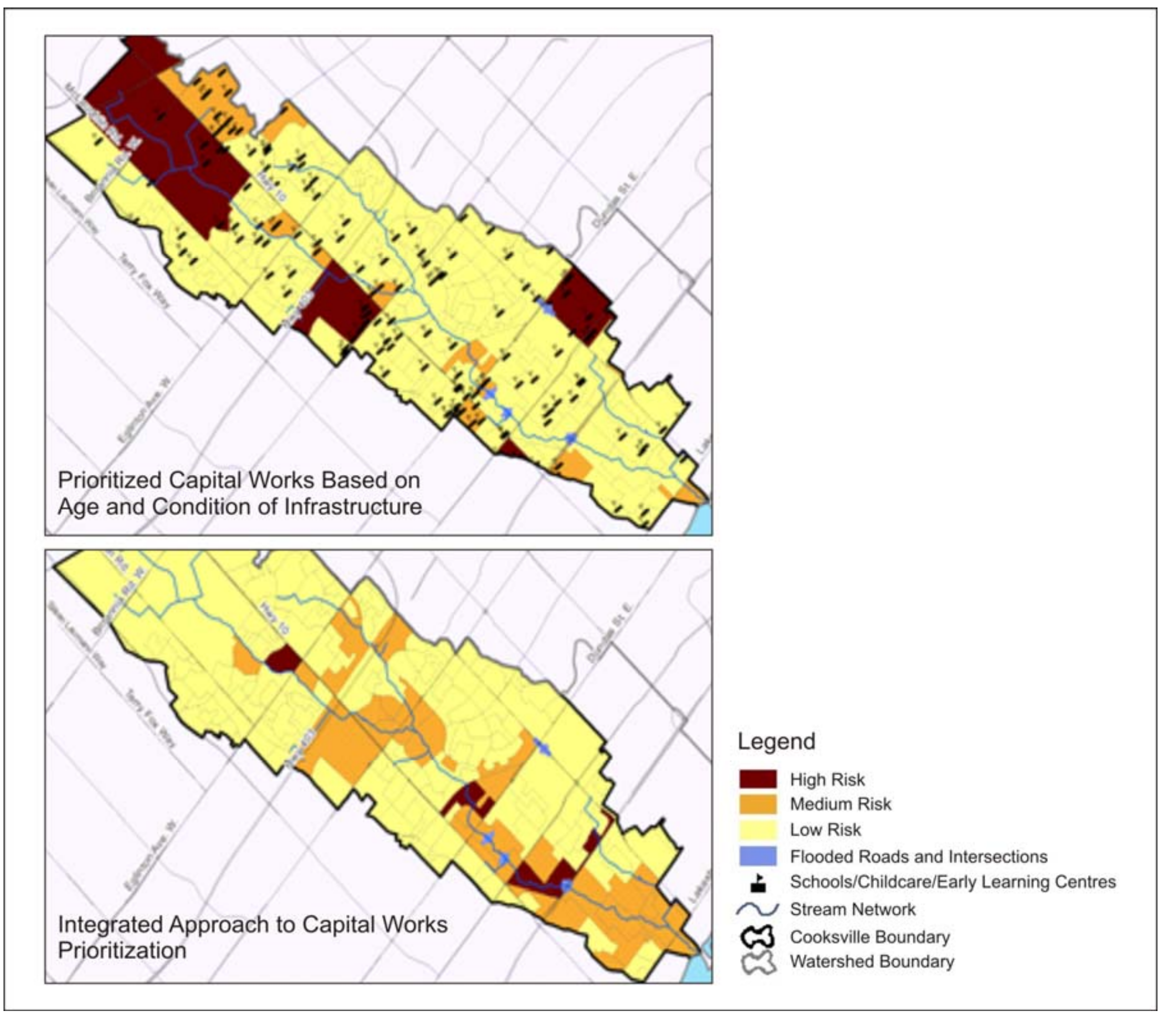
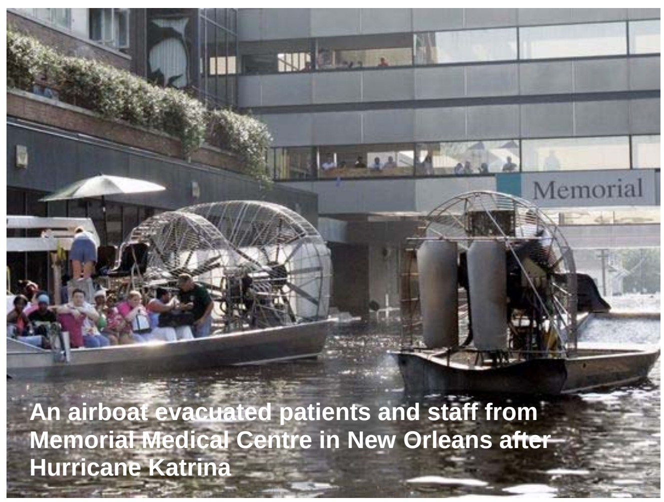



**Figure 5-2 Vulnerable Priority Areas of Critical Infrastructure (CVC et al, 2014)**

## Municipal Standards and Studies

**Metro Vancouver's (BC) Lion's Gate Wastewater Treatment Plant[37]:** The existing Lions Gate Primary Wastewater Treatment Plant, servicing the North Shore Communities of Metro Vancouver, will be replaced by a new secondary wastewater treatment plant by 2020. In upgrading the Lions Gate plant, Metro Vancouver embarked on an Integrated Design Process (IDP) that is proving to realize this project's potential to demonstrate Metro Vancouver's commitment to sustainability, provide leadership, and build a model wastewater treatment facility, while fulfilling its mandate of provision of a core service. The design considered many issues including visual aesthetics, odour control, truck traffic, noise, resiliency to sea-level rise, other climate change factors and future adaptability, and costs to taxpayers.




An airboat evacuated patients and staff from Memorial Medical Centre in New Orleans after Hurricane Katrina

**Developing Resilience to Extreme Events[38]:** The Lower Mainland Facilities Management group of Fraser Health in British Columbia developed *The Strengthening Hospital Resilience to Extreme Events* project - the first in British Columbia to assess both physical and social resilience of hospitals to extreme events and to identify actions to shape site-level adaptation plans. The project outcomes intend to inform healthcare organizations' ten-year mitigation and adaptation plans newly required by the province. In Phase 1, high-level resilience assessments were conducted in five hospitals, producing fifteen (15) recommendations applicable to any site.

**City of Vancouver, BC – Flood Construction Levels Bylaw:** The City has also advanced a bylaw focused on establishing increased flood construction levels as a response to the increased risk of flood damage due to climate change. To address increasing flood risk, the City requires buildings built today to be designed for flood resilience throughout their lifespan (City of Vancouver, 2014).

An example of the new bylaw's application is the Harbourside mixed-use development in North Vancouver, BC which will occupy three blocks of partially developed land running parallel to the waterfront. The new BC guidelines and City of Vancouver bylaws, taken together with projections

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[37] Photo Credit: http://watercanada.net/wp-content/uploads/2015/01/page8-1.jpg

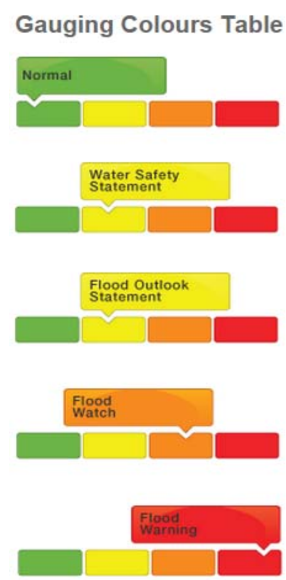
[38] Photo Credit: http://www.gannett-cdn.com/-mm-/e3ec6cba42dc452f36a1dee50c91e472529f7f8d/c=499-0-1937-1081&r=x408&c=540x405/local/-/media/2015/08/28/USATODAY/USATODAY/635763580514795165-Katrina-hospital-082815-2.jpg

of storm surge risks, local wind exposure, sea depth, and related wave effects, required flood construction level targets to be significantly higher than the previous minimum building elevations. To avoid construction of a dike, which would have blocked the water view, the design raises the waterfront retail, hotel, and residential buildings up to flood-proof level. Waterfront roads and convenience parking are also brought to the same level, about 1.75 m (6 feet) above existing grade, to provide indoor/outdoor access for retail and café uses (Golder, 2017).

**City of Moncton, NB - Flood Resilience:** The communities of Moncton, Dieppe and Riverview completed a Climate Change Adaptation project which informed the adaptation of sewage, drainage and flood defense infrastructure to climate change impacts in the Greater Moncton area (City of Moncton, 2013b). The City previously addressed the risk of flooding by requiring a minimum floor elevation for all new buildings, based on flood elevation levels from the 1869 Saxby Gale Flood event (City of Moncton, 2012). The Climate Change Adaptation project has assisted the City determine how sea level rise in the future may affect the city's infrastructure and identify flood-prone areas of the city. As a result, new structures are protected from the potential risk of flooding by requiring that the minimum geodetic elevation of occupied floor space or indoor parking areas is set 0.3 m higher than the previous requirement (City of Moncton, 2013a).

## Tools and Programs

**Credit Valley Conservation (CVC) Flood Forecasting and Warning Program**: CVC's Flood Forecasting and Warning Program focuses on predicting floods and communicating flood warnings and flood-related information to municipal partners, the public and interested ministries/agencies. The program includes three primary components: flood forecasting, flood monitoring and communication, and flood response. CVC is currently upgrading its flood forecasting methodology to develop enhanced predictive models, tools, and communication protocols that maximize the utility of CVC's real-time weather and streamflow gauge networks. For example, CVC is developing methods to obtain real time precipitation radar and forecasts (gridded data), correct/calibrate the data with measurements from rain gauges and then to run an enhanced hydrologic model to predict peak flows. CVC is also investigating various hydrologic model software packages since the type of required hydrologic model may differ depending on location (e.g. rural versus urban) and type of flooding (e.g. snowmelt versus thunderstorms).




**New Tools:** The University of Western Ontario has developed a "*Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate*" (UWO, 2016). This computerized web-based IDF tool integrates a user interface with a Geographic Information System (GIS). By creating or selecting a station, the user is able to carry out statistical analysis on historical precipitation data, as well as generate and verify possible future change based on a methodology using a combination of global climate modeling outputs and locally observed weather data.

The Ontario Ministry of Transportation (MTO) has implemented a number of recent updates to its IDF relationships to ensure they are as current as possible and regularly incorporate additional and recent rainfall data. MTO has also developed an IDF modeling tool[39] to generate a unique rainfall intensity curve for any point or area in the province. The most recent update to this tool has also included a predictive modeling component to enable generation of future IDF relationships accounting for the predictive impacts of climate change. MTO has updated drainage design policies for provincial highways, where drainage infrastructure is now designed for a predictive future flow rather than historical flow.

The Transportation Association of Canada (TAC) has recently initiated a project titled *Risk Analysis and Responding to Climate Change*. The underlying purpose of this project is to develop a web-based tool that encompasses a climate change risk assessment process for use by transportation agencies/infrastructure owners in Canada to assist in the assessment of the resilience of transportation infrastructure related to climate change.

[39] Available via URL: http://www.mto.gov.on.ca/IDF_Curves/

# 6.0 Opportunities to Increase Climate Change Adaptation

## 6.1 Summary

This chapter reviews specific opportunities for improving climate change adaptation for buildings and infrastructure in Canada. Opportunities presented in this report have been frequently identified in the adaptation literature and by subject matter experts consulted for the production of this report.

The key challenges in adaptation planning are the uncertainty of climate change events and the unforeseen impacts resulting from them. Adaptation to climate change will require modifications in planning and design approaches for infrastructure and buildings to address the increasingly extreme and volatile climate, with focus on some important areas such as:

- Development of guidelines, codes, standards, specifications, etc. that take into consideration the expected climate change impacts.
- Development of critical infrastructure inventories including the evaluation of vulnerabilities and identification of priority at-risk areas, based on the projected impact due to climate change.
- Identification of areas of high risk based on recent events (e.g. new flood zone mapping).
- Completion of risk and cost benefit analyses on alternatives to support decision-making on priority adaptation actions.
- Review of strategies and standards being used by other organizations (perhaps in other geographies) that have current weather similar to what is expected (i.e., very hot places already have designs that are adapted to hot weather).
- Incorporation of area specific storms and other extreme weather events in the assessment of infrastructure and building vulnerability, including identification of possible adaptation measures based on risk assessment.
- Integration of planning and decision-making amongst departments within an organization or amongst stakeholders.

The development of comprehensive site-scale vulnerability assessments that incorporate the above concepts should also be promoted.

## 6.2 Opportunities

Barriers to climate change adaptation in Canada most frequently mentioned in the literature and in conversations with subject matter experts completed for this State of Play report were:

- Inconsistent and lack of climate change guidance and direction at the provincial and federal levels.

- Need for municipal direction on how to define a risk tolerance, particularly within existing urban areas.
- Need for municipal direction on how to set design goals for infrastructure to meet the needs of future climate within its lifespan.
- Lack of defined roles and responsibilities for water infrastructure creates confusion and lack of integrated adaptation strategies.
- Lack of engineering tools to support optimization of adaptation measures or the financial tools to make an effective business case for adaptation action for municipalities who have been proactive and have completed infrastructure risk assessments.
- Lack of funding to implement adaptation initiatives.
- Lack of streamlined climate change data resources to accelerate implementation.
- Lack of public awareness of climate change and the need for making adaptation changes now.

To address these barriers, a list of sixty-two (62) opportunities or next steps has been developed through this State of Play study as summarized in the following:

### 6.2.1 All Governments, Organizations and Private Groups

1. Assessment of potential infrastructure interdependencies with the view to identification of risks which left unaddressed in their sector/organization could become secondary risks to others and vice versa.
2. Development of indicators to measure the success of adaptation measures or outcomes of adaptation policy.
3. Development of asset inventories or frameworks for asset management given that having a proper inventory of existing assets and their condition is a necessary first step to integrating climate change adaptation considerations into infrastructure planning.
4. Development of an outreach and engagement strategy to support the development of awareness of the availability and uptake of climate change adaptation guidelines, plans and protocols that are available.
5. Development of goal-oriented policies and objective-based standards for decision-making.

### 6.2.2 Federal Government

6. Development of key policies, regulatory and financial tools, in partnership with Provinces and Territories, that include processes to enable the integration of climate change adaptation considerations into infrastructure decision-making, design and maintenance.
7. Development of a unified approach to updating Intensity-Duration-Frequency (IDF) relationships, including projections, and design standards for stormwater management.
8. Development of a one-window, unified, climate resource centre that provides the foundational information and access to climate data and information locally and regionally. The centre could provide open and equitable access to a variety of information including climate change, water,

land and natural resources, transportation, as well as socioeconomic information. The climate resource centre could provide an opportunity for all adaptation experts from various disciplines to come together and help decision-makers and practitioners develop innovative responses to climate change impacts.

9. Enhancement of investment in atmospheric, hydrometric, infrastructure and groundwater monitoring to enhance knowledge and understanding of these systems and how they interact.
10. Development of a framework for dedicated funding for assessment of climate change risks/vulnerabilities, provision of consistent future data, updating flood maps and models, implementing infrastructure upgrades, and developing adaptation plans.
11. Update of existing building codes and standards to incorporate climate change and advancements in climate knowledge and climate impacts such as costs and social disruption.
12. Development of a sustainability and resiliency self-assessment rating system and report card for infrastructure and building systems.
13. Development of performance monitoring and reporting guidelines, in partnership with Provinces and Territories, to identify future infrastructure needs in an effort to enhance communities and develop better systems in the future.
14. Development of guidelines focused on resilient systems, which include adaptability to climate change and community growth, as well as recovery from extreme events.
15. Development of quality management standards for stormwater and wastewater.
16. Enhancement of risk-based prioritization tools to evaluate and prioritize infrastructure needs, to include consideration of social vulnerabilities.
17. Development of standards to perform forensic accounting of extreme events in an effort to build a database that includes financial and service risks and costs.
18. Development of an up-to-date infrastructure deficit estimate, in coordination with Provinces and Territories.

### 6.2.3 Provincial Government

19. Development of provincial regulations to incorporate climate change resiliency in new, existing and redevelopment areas.
20. Development of clear guidance on how to interpret provincial policies that address climate change.
21. Development of a one-window central repository for climate data including localized climate projections and provincially adopted future climate data sets.
22. Development of goal-oriented approaches, as opposed to prescriptive approaches, for infrastructure sizing. Goal-oriented policies can be more quickly enacted, whereas updating guidelines/ standards is a slower process.
23. Development of quality management standards for stormwater and wastewater infrastructure and provide the basis for political engagement, commitment and endorsement.

24. Incentivization of source controls such as low impact development/green infrastructure to mitigate erosion impacts, promote groundwater recharge and support the implementation of water treatment technologies for nutrient removal.
25. Development of a systems approach in managing drinking water, wastewater and stormwater systems that includes a watershed approach, as defined by integrated water resources management.
26. Preservation and restoration of critical wetlands and other natural infrastructure.

#### 6.2.4 Municipal Government

27. Dedication of budgets for capital and operations work related to climate change adaptation.
28. Development of municipal/public partnerships to explore options for adaptation on private property.
29. Incorporation of adaptation into municipal planning policy.
30. Integration of planning, capital works, and emergency services to optimize investment and reduce risks to vulnerable populations.
31. Development of standards for flood proofing of wastewater and water treatment plants, and other infrastructure and buildings, to address climate change risks (vulnerability to extreme rainfall or short duration and high intensity rainfall events).
32. Development of standards for climate resilient chemical/materials management and storage in treatment facilities.
33. Development of standards for drinking water infrastructure to support determination of chemical reserves, material process requirements and capacities to include the potential for increased water demand in drought conditions / consecutive dry days.
34. Development of a standard for water conservation programs for municipalities.
35. Development of better informed emergency management plans for infrastructure failures or extreme weather emergencies.
36. Development of better coordination with regard to heat alert notifications. For example having water and wastewater operators ensure that proper cooling measures and back-up power generators are in place.
37. Development of integrated asset management plans (operations and maintenance).
38. Development of a risk-based prioritization tool with a variety of municipalities (sizes and location) to provide a standard approach for municipalities to evaluate and prioritize their infrastructure needs.
39. Identification of learning needs and provision of necessary training to enhance municipal internal functionality and communications (i.e.: operations, engineering and finance groups).
40. Development of terms of reference and on-going support for “peer-to-peer” communications amongst municipal groups for asset management planning and sustainability plans.

41. Development of standardized practices guides for small communities adapting to extreme rainfall.
42. Development of communication strategies and tools targeted to the public and elected officials to promote understanding and value of infrastructure and the need for investment to build resilient systems.
43. Endorsement of water-related policies to ensure proper implementation at the municipal level. For example, in Ontario's Safe Drinking Water Act, municipal councillors are personally liable for their drinking water systems and to ensure that the appropriate actions are being taken to address potential climate change impacts.
44. Build resilience into community access and transportation systems planning and development.
45. Prioritization of areas of high climate change vulnerability/risk for implementation of adaptation measures.

### 6.2.5 Private Companies (Insurance, Consulting, etc.)[40]

46. Inclusion of climate change and adaptation in professional training and education programs (e.g., design of green infrastructure as part of water resources engineering training).
47. Development of an understanding of the risks and opportunities posed by climate change.
48. Build climate resilience into corporate assets and decision-making.
49. Encourage the use of data needed to make good decisions; if the company does not have all of the information needed, find ways to access it.
50. Encourage long-term planning taking into consideration climate change.
51. Encourage understanding of implications/risks of climate change to the business. These include disclosures by public companies due to regulatory obligations, increased shareholder interest and reporting issues. Climate Change and Related Disclosures will assist with education and awareness-building of mitigation, adaptation, and operational and financial impacts.
52. Encourage the use of best practices and standards in corporate programs.
53. Participation in the standards development process.
54. Development of clear understanding of climate change reporting requirements.
55. Better integration of climate change considerations into organizational planning, decision-making and risk management processes.
56. Exercise due diligence as asset owners/operators and integrating climate considerations into asset management plans and infrastructure investment plans.

[40] CPA, 2016

57. Collaborate and engage across disciplines to enhance understanding of potential impacts and future changes on their assets and operations.

### 6.2.6 Industry and Professional Associations

58. Encourage membership to consider and support implementation of adaptation and mitigation actions.
59. Provide training to membership with a goal to ensure that professionals can advise capably on adaptation. Consider making such training mandatory.
60. Consider participation in the standards development process.

### 6.2.7 Customers and Citizens

61. Development of public awareness programs that increase knowledge of climate change and the need for adaptation.
62. Consider participation in the standards development process.

While it has been recognized that actions advancing climate change adaptation are not consistent across Canada, some jurisdictions and organizations have been, and are, making advancements in these areas of opportunity.

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# Appendix A
# Infrastructure Standards

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## Appendix A – Infrastructure Standards

### Table A.1: National Drinking Water, Wastewater Effluent and Stormwater Infrastructure Standards

| | Criteria | | Microbiological Parameters | | | | | Chemical/Physical Parameters | Radiological Parameters |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Enteric protozoa** | **Enteric viruses** | **Escherichia coli** | **Total coliforms** | **Turbidity** | **Based on health, aesthetic and operations - existing Maximum acceptable concentrations** | **Radioactivity using gross alpha and gross beta** |
| **Drinking Water** | **Federal Standards** | | Treatment goal: Minimum 3 log removal and/or inactivation of cysts and oocysts | Treatment goal: Minimum 4 log reduction (removal and/or inactivation) of enteric viruses | Maximum acceptable concentration: None detectable per 100 mL | Maximum acceptable concentration: none detectable/100 mL in water leaving a treatment plant and in non-disinfected groundwater leaving the well | Treatment limits for individual filters or units: Conventional and direct filtration: ≤ 0.3 NTU slow sand and Diatomaceous earth filtration: ≤ 1.0 NTU Membrane filtration: ≤ 0.1 NTU | Visit link for a wide range of parameters and the associates MACs | Concentrations of specific radionuclides should be analysed if 0.5 Bq/L for gross alpha and 1.0 Bq/L for gross beta), |
| | | | Health Canada. (2014). Guidelines for Canadian Drinking Water Quality - Summary Table. Retrieved from: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/index-eng.php#t1 | | | | | | |
| | **Provincial Standards** | Ontario | + | + | + | + | + | + | + |
| | | Newfoundland & Labrador | + | + | + | + | + | + | + |
| | | Nova Scotia | + | + | + | + | + | + | + |
| | | New Brunswick | + | + | + | + | + | + | + |
| | | Prince Edward Island | + | + | + | + | + | + | + |
| | | Quebec | + | + | + | + | + | + | + |
| | | Manitoba | + | + | + | + | + | + | + |
| | | Saskatchewan | + | + | + | + | + | + | + |
| | | Alberta | + | + | + | + | + | + | + |
| | | British Columbia | + | + | + | + | + | + | + |
| | | NWT | + | + | + | + | + | + | + |

| | Criteria | | Bacterial Standard | Chemical/Physical Standards | | | | | Combined Sewer Overflows (CSOs) |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Bacterial Count** | **CBOD (5 day BOD test)** | **TSS** | **Total Ammonia** | **pH** | **Total Residual Chlorine** | |
| **Wastewater Effluent** | **Federal Standards** | | 200FC/100 mL | Monthly/Quarterly average <= 25 mg/L | Monthly/Quarterly average <= 25 mg/L | Monthly/Quarterly Max. Concentration less than 1.25 mg/L | pH standard not listed for effluent discharged to water body | Monthly/Quarterly Average less than or equal to 0.02 mg/L<br><br>Total residual Chlorine standard not listed for effluent discharged to water body | Need to report the volume or estimated volume of effluent deposited via overflow point for the month in $m^3$ Number of days effluent was deposited in the month |
| | Government of Canada. (2012). Fisheries Act - Wastewater Systems Effluent Regulations. Retrieved from: http://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-139/FullText.html | | | | | | | | |
| | **Provincial Standards** | Ontario | + | + | + | + | + | + | + |
| | | Newfoundland & Labrador | + | + | + | + | + | + | + |
| | | Nova Scotia | + | + | + | + | + | + | + |
| | | New Brunswick | + | + | + | + | + | + | + |
| | | Prince Edward Island | + | + | + | + | + | + | + |
| | | Quebec | + | + | + | + | + | + | + |
| | | Manitoba | + | + | + | + | + | + | + |
| | | Saskatchewan | + | + | + | + | + | + | + |
| | | Alberta | + | + | + | + | + | + | + |
| | | British Columbia | + | + | + | + | + | + | + |
| | | NWT | *Undergoing research* | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Criteria** | | **Flooding** | **Erosion** | **Water Quality** | **Water Balance** |
| **Stormwater** | **Federal Standards** | | No guidelines | No guidelines | No guidelines | No guidelines |
| | **Provincial Standards** *See Table A.2 for more details.* | Ontario | + | + | + | + |
| | | Newfoundland & Labrador | + | No guidelines | No guidelines | No guidelines |
| | | Nova Scotia | + | + | + | + |
| | | New Brunswick | + | No guidelines | No guidelines | No guidelines |
| | | Prince Edward Island | + | No guidelines | No guidelines | No guidelines |
| | | Quebec | + | No guidelines | No guidelines | No guidelines |
| | | Manitoba | + | No guidelines | No guidelines | No guidelines |
| | | Saskatchewan | + | + | + | + |
| | | Alberta | + | + | + | + |
| | | British Columbia | + | + | + | + |
| | | NWT | + | No guidelines | No guidelines | No guidelines |

### Table A.2: Provincial Stormwater Standards

| Province | Flooding | Erosion/Water Quality/Water Balance |
|---|---|---|
| Newfoundland & Labrador | Water resources division indicates they complete climate change flood risk mapping studies.<br><br>Province identifies that rainfall the leading cause of floods - the Province has flood risk mapping and flood forecasting but has little to no information on flood control strategies. A policy does exist for floodplain management. For projects where floodplains are designated: the ground floor elevation of the structure is higher than the 1:100 year flood level and the climate change flood zone (where designated), the structure will not interfere with the flow of water or displace water such that it creates a worse flooding situation for other properties.<br><br>See details at http://www.env.gov.nl.ca/env/waterres/regulations/policies/flood_plain.html | No Provincial SWM guidelines found provincial on website. Very little information in general on stormwater runoff and quality control on water resources management section of website: http://www.env.gov.nl.ca/env/waterres/.<br><br>Environmental Standards for Municipal Solid Waste Landfill Sites, 2010 has some information on stormwater management:<br>“Storm water management systems shall be designed to handle a 100 year storm event for a duration appropriate to the size of the drainage basin. Sedimentation pond construction specifications shall be provided in the application. Discharge from a sedimentation pond shall meet the Environmental Control Water and Sewage Regulation, 2003 as listed in the separate Appendix C. For parameters of concern that are not addressed by the regulations, the appropriate CCME Water Quality Guidelines will apply. If compliance monitoring and sampling indicates problems, then corrective action must be taken immediately.” (Government of Newfoundland and Labrador, 2010)<br><br>Environmental Control Water and Sewage Regulation, 2003:<br>Appendix C referred to above and this regulation document do not explicitly say what the quality of discharge should be from the sedimentation ponds specifically. The below information is for effluent in general:<br>A person shall not discharge into a body of water sewage or effluent<br>(a) containing a constituent specified in Column 1 of Schedule A having a content in milligrams per litre in excess of the maximum specified in Column 2 of that Schedule<br>(b) having a temperature in excess of 32° Celsius<br>(c) having a pH value less than 5.5 or greater than 9.0; or<br>(d) a radio-active substance having a gross beta activity before discharge of more than 37 Bq per litre with the exception of<br>(i) radium 226 which shall not exceed 0.37 Bq per litre, and<br>(ii) strontium 90 which shall not exceed 0.37 Bq per litre |
| Nova Scotia | The 100-year flood has been used to delineate and designate flood plains.<br>The two zone approach has been used where future development is prohibited in the floodway, defined by the 20-year flood, but is permitted in the flood fringe if adequate flood proofing is carried out. | Water resources management strategy we released in 2010;<br>This document is a 10 year strategy and not specific to stormwater but identifies that changes to the natural water cycle are possible in part due to climate change (more intense storms). Document indicates that province must be prepared for changes in the amount of precipitation during storms, and changes in storm frequency and intensity. Identifies that intense storms cause more erosion, and don't give the ground enough time to absorb the water that replenishes groundwater aquifers.<br>An action outlined in the management strategy for the protection of the quality and quantity of the water is “Update current guidance for storm water management and sediment control to improve protection of water quality from land development activities.” (Government of Nova Scotia, 2010)<br><br>Stormwater management guidelines for municipality of Halifax:<br>https://www.halifax.ca/energy-environment/environment/documents/HRMStormwaterManagementGuidelines2006.pdf |
| New Brunswick | Most of the flood risk mapping for New Brunswick was developed in the 1970s. There is current no provincial initiative to systematically update the existing flood risk mapping.<br>• One zone approach used<br>• 100 year flood used to delineate floodplain<br>• Climate change not taken into account | No information on stormwater management on provincial website. The provincial website does have some information on climate change indicated more frequent melt events and the increase of precipitation intensity. Provincial website lists adaptations to climate change. Some of the more relevant adaptations listed are designing storm water systems to handle increased precipitation; and installing barriers and using other erosion-control methods.<br>Province is working towards a water strategy for New Brunswick<br><br>Municipalities that have SWM plans. Links to plans for Moncton and Saint John are listed below<br>http://www.saintjohn.ca/site/media/SaintJohn/Storm%20Drainage%20Design%20Criteria%20Manual.pdf<br><br>https://www.moncton.ca/Assets/Government+English/Department+English/Engineering+and+Environmental+Services/Engineering+Design+Criteria+Manual.pdf |
| Prince Edward Island | Some info at<br>https://www.princeedwardisland.ca/en/information/communities-land-and-environment/coastal-erosion-and-flood-risk-assessment<br>Climate change / SLR recognized in assessment of coastal circumstances re development | Technical Manual for Watershed Management on Prince Edward Island: http://peiwatershedalliance.org/TechManual/Technical_Manual.pdf<br><br>Document speaks of SW challenges, however does not give guidelines for SWM. The document identifies the consequences of surface water runoff on water quality (pesticide spikes from stormwater runoff). The document also talks about climate change and the increased frequency of extreme storms. It indicates the "larger centres like Charlottetown and Summerside will experience greater pressure on storm-water and sewer systems in extreme rain storms."<br><br>This document also makes reference to green infrastructure "“Green” storm water management is also in its infancy on the Island. Green infrastructure is a growing trend in North America and often alleviates multiple issues with storm-water, including flooding of basements, sedimentation of waterways, poor recharge to groundwater and pollution control." It explains Toronto's initiatives for implementing Green infrastructure. |

| Province | Flooding | Erosion/Water Quality/Water Balance |
|---|---|---|
| Quebec | The floodplain is divided into two zones, the floodway, where further development is discouraged, and the flood fringe where flood proofed development is possible. However, there are some exceptions. With Ministerial approval," derogation" permits a specified project to be undertaken within a specified area of the floodway. | Established requirements in 2012: http://www.mddelcc.gouv.qc.ca/eau/pluviales/index-en.htm<br>Documents are in French<br><br>There are no mandatory provincial requirements specifically for stormwater; instead, best practices and examples are provided. The following documents are in English: http://glslcities.org/wp-content/uploads/2015/05/Stormwater-Management-Report_English_Final2_Updated_June11.pdf<br><br>https://www.fcm.ca/Documents/presentations/2016/webinars/Green_Stormwater_Infrastructure_in_Quebec_Integration_in_the_Urban_Fabric_Melanie_Glorieux_EN.pdf |
| Ontario | Provide post- to pre- control for all design storms<br>(2, 5, 10, 25, 50 and 100 year)<br><br>Ontario building code<br>1) requires rooftop downspout disconnection<br>2) does not consider increased impervious cover in renovation permits hence accepting additional stormwater (calculations show that impervious cover can increase by 15-20% resulting in more stormwater runoff production and potential flooding) | Erosion<br>- Minimum detain 5 mm on site<br>- Site with ponds, 25 mm - 48hr detention may also be required<br><br>Water Quality<br>- Enhanced Level of Protection (80% TSS removal) as per the latest MOE SWMPD manual is required.<br><br>Water Balance<br>- For significant, ecologically significant, high volume and medium volume groundwater recharge areas, maintain pre-development protection of related hydrologic and ecologic functions.<br>- For low groundwater recharge areas, a minimum of 3 mm of groundwater recharge per event post development.<br><br>(MOECC, 2003) |
| Manitoba | Manitoba uses a 2 - zone concept but it is founded more in the type of flood protection that can be used.<br><br>The floodway fringe is defined as the area which, if removed from the active flow zone, would raise the water level by less than 0.3m.<br><br>The design event is the flood of record plus 0.6m or the 100 year event. The Province is moving to the 200 year event.<br><br>There is some talk about including some aspect of climate change, but our flooding is so widespread that we haven't caught up with current requirements, so not yet.<br><br>The design event for critical infrastructure, such as the City of Winnipeg, is the event that can be justified through a benefit cost analysis. It is currently the 1:700 year event for Winnipeg. | Sustainable Stormwater Management Guide for school grounds, public spaces and midsize commercial properties, 2013: http://greenmanitoba.ca/umedia/Water-on-the-Land-Mar_1-2013.pdf<br>This is not a very formal document and is more of a very general guidance document. This is not a guidance document on design standards for developers, planners, etc.<br><br>Manitoba has a water strategy document, it was released in 2003:http://www.gov.mb.ca/sd/waterstewardship/waterstrategy/pdf/water-strategy.pdf<br>Document does not speak about stormwater but recognizes that with climate change more frequent spring flooding and periods of summer drought needs to be addressed. Document indicates that the Manitoba understands of the effects of climate change needs to improve. An action in this document is to "Determine possible effects of climate change on water supplies and study options to deal with and adapt to these potential changes."<br><br>There is also an "Applying Manitoba's Water Policy" document: http://www.gov.mb.ca/sd/waterstewardship/licensing/mb_water_policies.pdf<br>There are a couple policies relevant to stormwater however this document does not contain specific design criteria. They are below:<br>Conservation POLICY 2.4: Water retention, and control and timing of runoff, shall be promoted as part of watershed management.<br>Drainage POLICY 6.1: Drainage works shall be designed to remove excess rainfall from cropland during the growing season.<br>Drainage POLICY 6.7: Water retention, and control and timing of runoff, shall be promoted as part of watershed management.<br><br>Manitoba Surface Water Management Strategy:<br>http://www.gov.mb.ca/sd/waterstewardship/questionnaires/surface_water_management/pdf/surface_water_strategy_final.pdf<br>Strategy does not have specific design criteria. Document is high level direction under three pillars:<br><br>1) Improving and Protecting Water Quality<br>2) Preparing for Extreme Events<br>3) Co-ordination and Awareness |

| Province | Flooding | Erosion/Water Quality/Water Balance |
|---|---|---|
| Saskatchewan | This includes the requirement that development be prohibited in the floodway of the 1:500 year flood elevation of any watercourse or water body and that new development in the flood fringe of a 1:500 year flood be flood proofed to an elevation 0.5 metres above the 1:500 year flood elevation. See https://www.saskatchewan.ca/government/municipal-administration/community-planning-land-use-and-development/subdivision-zoning-and-land-use/land-use-planning-and-flood-management. The minor and major (piped) systems should be designed for 1:5 and 1:100 year events, respectively. End-of-pipe controls, such as wet ponds or dry ponds should be designed for 1:100 year event with a safe overflow route so as to avoid flooding for large events. 24 hour detention time for wet/dry ponds and constructed wetlands. | Stormwater Guidelines, 2014: http://www.saskh20.ca/DWBinder/epb322.pdf<br><br>Under The Environmental Management and Protection Act, 2002 (EMPA) and The Water Regulations, 2002; stormwater quality and most aspects of its management at present is not specifically regulated.<br>The purpose of this guideline is to provide a high-level technical guidance to municipal authorities, individuals and consultants who plan to develop and implement drainage systems for stormwater in urban/built-up municipal areas, commercial and industrial areas in Saskatchewan.<br><br>Stormwater management solutions are site specific, which must be recognized when using the guidance provided in this document. The designer has to determine if a single practice or a combination of practices are needed to meet the stormwater objectives and goals for any given site and is responsible for the design and decisions made with respect to stormwater management |
| Alberta | 1. Two zone approach<br>2. Not defined by rainfall here; rather 1:100 year average recurrence interval (ARI) flood discharge or same ARI ice induced water level.<br>3. Climate change is considered but documentation provided to date points to no statistical evidence of change.<br><br>Dual Drainage Concept<br>Minor Systems: In larger urban centers in Alberta the return period for minor system design most commonly used is the 1-in-5 year event<br>Major Systems: more variation in the selection of design standards for the major system because the major system is comparatively recent. The most commonly used major system design event is the 100-year event and is recommended for Alberta | SWM guidelines for Alberta are from 1999.<br>http://aep.alberta.ca/water/programs-and-services/municipal-wastewater-and-storm-water-management-program/documents/StormwaterManagementGuidelines-1999.pdf<br><br>Water Quality Control<br>BMP design criteria for stormwater quality control: In the absence of detailed studies in Alberta, it is considered that providing 25 mm of storage for the contributing are is appropriate for Alberta for SW quality control using detention devices such as dry ponds, wet ponds and constructed wetlands. A detention time of 24 hours should also be used for detention facilities since it is well established that for a detention basin to be effective as a quality control device, detention time much be 24 hours or greater.<br>Using the runoff from a 12-mm storm event over the contributing area is considered appropriate for infiltration BMPs |
| British Columbia | 200-year flood defines the flood risk area, but in two zones, the floodway, where further development is discouraged, and the flood fringe where flood proofed development is possible. Metro Vancouver is in the midst of developing a new WWTP at Lion's Gate. The flood assessment to establish the Flood Construction Level (FCL) did incorporate the potential for climate change to influence SLR, storm surge and rainfall.<br><br>Objectives for Protecting Watershed Health in the Urban Environment<br>The three sets of objectives for a truly healthy urban watershed. The purpose is to provide an integrated framework for guiding the actions of local governments within their sphere of responsibility and influence.<br>Water Balance<br>Objective 1 - Preserve and protect the water absorbing capabilities of soil, vegetation and trees.<br>Objective 2 - Prevent the frequently occurring small rainfall events from becoming surface runoff.<br>Hydrology / Water Quality<br>Objective 3 – Provide runoff control so that the Mean Annual Flood (MAF) approaches that for natural conditions.<br>Objective 4 – Minimize the number of times per year that the flow rate corresponding to the natural MAF is exceeded after a watershed is urbanized.<br>Objective 5 – Establish a total suspended solids (TSS) loading rate (i.e. kilograms per hectare per year) that matches pre-development conditions.<br>Objective 6 – Maintain a baseflow condition equal to 10% of the Mean Annual Discharge (MAD) in fisheries-sensitive systems.<br>Biophysical<br>Objective 7 - Limit impervious area to less than 10% of total watershed area.<br>Objective 8 - Retain 65% forest cover across the watershed.<br>Objective 9 - Preserve a 30-metre wide intact riparian corridor along all streamside areas.<br>Objective 10 - Maintain B-IBI (Benthic Index of Biological Integrity) score above 30. | Hydrology Objectives for Protecting Watershed Health (Erosion Control)<br>In terms of mitigating the impacts of impervious area on watershed hydrology, British Columbia case study experience has resulted in identification of the following hydrology based objectives for a truly healthy watershed:<br>Objective 3 – Provide runoff control so that the Mean Annual Flood (MAF) approaches that for natural conditions.<br>Objective 4 – Minimize the number of times per year that the flow rate corresponding to the natural MAF is exceeded after a watershed is urbanized.<br>Objective 6 – Maintain a baseflow condition equal to 10% of the Mean Annual Discharge (MAD) in fisheries-sensitive systems.<br><br>Water Quality Objectives for Protecting Watershed Health<br>Objective 5 – Establish a total suspended solids (TSS) loading rate (i.e. kilograms per hectare per year) that matches pre-development conditions.<br><br>Water Balance Objectives for Protecting Watershed Health<br>In terms of preventing land development and related human settlement activities in the urban environment from impacting the Water Balance, British Columbia case study experience has resulted in identification of the following objectives for a truly healthy watershed:<br>Objective 1 - Preserve and protect the water absorbing capabilities of soil, vegetation and trees.<br>Objective 2 - Prevent the frequently occurring small rainfall events from becoming surface runoff. |

| Province | Flooding | Erosion/Water Quality/Water Balance |
|---|---|---|
| Territories | Municipal SWM plans for Whitehorse and Yellowknife<br>Territories<br>Aboriginal Affairs and Northern Development Canada (AANDC) had a mandate to manage water resources in all of the Territories. On April 1, 2003, responsibility for the management of water resources in Yukon was transferred to the Government of the Yukon. On April 1, 2014, the Government of the Northwest Territories became responsible for managing public land, water, and resources in the NWT – This contradicts what is found on this website, however this website was last updated in 2013 so I suspect it is out of date and that Nunavut is the only territory where the water resources are federally managed: https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=24C5BD18-1<br><br>Yukon: Based on Yukon government website, Yukon acknowledges potential flooding risk as climate change will cause precipitation patterns to be altered (more rain and more extreme events). Also indicate warmer temperature associated with cause more melt, another flooding threat.<br>I did locate the "Yukon water strategy and action plan" but it does not include stormwater: http://yukonwater.ca/docs/default-source/default-document-library/yukon_water_strategy_action_plan.pdf?sfvrsn=0<br><br>Whitehorse watershed management plan: http://ww3.whitehorse.ca/Planning/watershed%20management/WMP_Volume_2.pdf<br><br>Northwest Territories: NWT water stewardship website identifies concerns related to aquatic ecosystems including the quality and quantity of the water and how these affect fish, wildlife and people that use the water. Website also indicates pressures on water include climate change and large-scale developments, such as mining and oil and gas, in the NWT.<br>The Waters Act provides the GNWT with authority related to the permitting and use of water and the disposal of waste in bodies of water in the territory. The Waters Act was established April 1, 2014. The Waters Act does not include stormwater: http://www.assembly.gov.nt.ca/sites/default/files/14-02-28_bill_14.pdf<br><br>In 2010 the "2010 Northern Voices, Northern Waters: NWT Water Stewardship Strategy" was released: http://www.enr.gov.nt.ca/sites/default/files/strategies/nwt_water_stewardship_strategy.pdf<br>The second Northwest Territories Water Stewardship Action Plan was released June 28, 2016 by the Government of the Northwest Territories. It represents the second five-year implementation phase of the NWT water stewardship strategy: http://www.enr.gov.nt.ca/sites/default/files/128-nwtws_action_plan2016_proof.pdf<br>Neither of these strategies includes stormwater<br><br>Nunavut: Does not have territorial website for water management. Aboriginal Affairs and Northern Development Canada's responsibility for water management is laid out in section 5 of the Department of Indian Affairs and Northern Development Act: http://laws-lois.justice.gc.ca/PDF/I-6.pdf | |

### Table A.3: Provincial Watershed Management Standards

| Province | Status on Integrated Watershed Management | Watershed Planning Guidance | Floodplain Management | Freshwater Quality(ECCC, 2016)(Environment Canada, 2015) | | | | | Forest Cover |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total Phosphorus | E. Coli | Benthic Macroinvertebrates | Nitrate-Nitrogen | Dissolved Chloride | |
| Newfoundland & Labrador | The province encourages the development of drinking water source protection committees and municipalities are responsible for forming watershed protection committees and provide funding for plan development (CCME, 2016). | The province provides a municipal guide for municipalities to develop Watershed Management Plans. However, there are no clear guidelines on watershed targets or in-stream targets (Hearn, 2007). | An area adjacent to a lake, river, seashore etc. which is inundated or covered with water on average at least once in 100 years. Note that a flood plain is considered to be an integral part of a body of water as defined above because it includes "the land usually or at a time occupied by that body of water" and "whether that source usually contains water or not" (EDC, 2016). | 0.03 mg/L | Geometric mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | 3 mg N/L | 120 mg/L | Provincial sustainable forest management strategy for 2014-2024. Looks into accountability and transparency through forest certification using the ISO 14001 Environmental Monitoring System. Adaptive management using environmental protection guidelines that are periodically updated (Government of Newfoundland and Labrador, 2014). |
| Nova Scotia | Has a senior-level interdepartmental committee to oversee and generate cross-departmental collaboration. The province encourages municipalities to develop source water protection plans and take an integrated watershed management approach (CCME, 2016). | The province provides a guide for water utilities and municipalities (Government of Nova Scotia, 2002).<br><br>No set guidance was found for defined in-stream targets/thresholds. | The 100-year flood has been used to delineate and designate flood plains. The two zone approach has been used where future development is prohibited in the floodway, defined by the 20-year flood, but is permitted in the flood fringe if adequate flood proofing is carried out. | 0.03 mg/L | mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | 3 mg N/L | 120 mg/L | Nova Scotia has a Code of Forest Practice which provides direction and practical guidance for the sustainable management of a range of forest uses and values to benefit present and future generations of Nova Scotians (Government of Nova Scotia, 2008). |
| New Brunswick | Has a watershed based group that are coordinated through the province and local municipalities via an environmental fund to engage in watershed planning activities (CCME, 2016). | No clear guidance on how to develop watershed plans.<br><br>The province provides a guide to new Brunswick's water classification regulation specifically for water quality (DOELG, 2002). | Most of the flood risk mapping for New Brunswick was developed in the 1970s. There is current no provincial initiative to systematically update the existing flood risk mapping. Therefore, the answer to your questions is as follows, which indicates the historical flood risk mapping:<br><br>· One zone approach used<br>· 100 year flood used to delineate floodplain<br>· Climate change not taken into account | 0.03 mg/L (rivers) and 0.02 mg/L (lakes) | Geometric mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | 2.9 mg/L | 120 mg/L | The province has a strategic forest management planning which is required under the forest management act and sets license requirements. The forest management plan sets out the direction for reporting the state of the forest in the future using forecasting models. The government define the goals and objectives within the management plan when approving and endorsing strategic review. To complement the forest management plan, licensees are also required to develop operating plans which is a key transparency element for harvesting purposes (Government of New Brunswick, 2004). |

| Province | Status on Integrated Watershed Management | Watershed Planning Guidance | Floodplain Management | Freshwater Quality(ECCC, 2016)(Environment Canada, 2015) | | | | | Forest Cover |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total Phosphorus | E. Coli | Benthic Macroinvertebrates | Nitrate-Nitrogen | Dissolved Chloride | |
| Prince Edward Island | The province has 26 community based watershed groups that focus on stream enhancement projects and now with dedicated provincial funding on watershed management, the group also engages in watershed planning activities (CCME, 2016). | General guidance exists on watershed planning dedicated to the protection and enhancement of natural resources and water quality. There is general mention of developing indicators to measure success but no clear direction on how to do so (PEIEEF, 2006). | Climate change / SLR recognized in assessment of coastal circumstances re development (Government of Prince Edward Island, 2016) | site-specific guidelines | mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | site-specific guidelines | - | The province provides guidelines for managers to prescribe/implement appropriate treatments in appropriate forest conditions. The province also has ecosystem-based forest management standards manual. The province does not allocate long term timber rights for public lands, but will enter into co-management agreements with groups and organizations that share a commitment to forest stewardship and who can implement work in compliance with the required standards contained in the Ecosystem-based Forest Management Standards Manual (PEIDAF, 2014). |
| Quebec | The province has developed integrated watershed management zones through an umbrella agency representing 40 watershed organizations (CCME, 2016). | - | The floodplain is divided into two zones, the floodway, where further development is discouraged, and the flood fringe where flood proofed development is possible. However, there are some exceptions. With Ministerial approval, "derogation" permits a specified project to be undertaken within a specified area of the floodway. | 0.03 mg/L | Geometric mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Réseau de suivi du benthos (RSBenthos) and Canadian Aquatic Biomonitoring Network (CABIN) (Pelletier & Armellin, 2012). | 3 mg N/L | - | The province sets out guidelines that require the owner to develop forest management plans over the next 5 years. It is the responsibility of the owner to develop and implement the management plan whereas the province only plays a supervisory role (Government of Quebec, 2012). |
| Ontario | Ontario's conservation authorities deliver watershed based programs for member municipalities including review of and comment on growth and development plans, zoning bylaws, from the perspective for the watersheds (CCME, 2016). | Guidance document on Subwatershed Planning provides the "why, when and how" to prepare subwatershed plans to promote an ecosystem-based approach, foster early integrated planning, assist local governments and enhance efficiency and effectiveness of land use planning.<br><br>With respect to targets, the subwatershed planning process requires setting targets and constraints to understand how well the subwatershed plan meets the watershed plan objectives (MOEE, 1993). | Floodplain delineated for the regulatory storm (greater of Hurricane Hazel or the 100 yr.)<br><br>Generally, accepted criteria are that maximum peak (site) flow rates must not exceed pre-development values for storms with return periods ranging from 2 to 100 years (MOECC, 2013) | 10 µg/L (protect against aesthetic deterioration)<br>20 µg/L (to avoid algae)<br>30 µg/L (to avoid excessive plant growth in rivers/streams) | Geometric mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Ontario Benthos Biomonitoring Network: Protocol Manual developed by the province. The manual sets the measurement requirements to identify the abundance such as counts, enumerations, composition and diversity. | 2.93 mg/L | 120 mg/L | Forest Management Planning Manual for Ontario's Crown Forests sets the framework sets broad direction for forest policy and makes forest sustainability the primary objective of forest management (OMNR, 2009). |

| Province | Status on Integrated Watershed Management | Watershed Planning Guidance | Floodplain Management | Freshwater Quality(ECCC, 2016)(Environment Canada, 2015) | | | | | Forest Cover |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total Phosphorus | E. Coli | Benthic Macroinvertebrates | Nitrate-Nitrogen | Dissolved Chloride | |
| Manitoba | The province implements integrated watershed management through conservation districts with a watershed planning authority to develop an integrated watershed plan (CCME, 2016). | The province provides a guidance document on Integrated Watershed Management Planning (Manitoba P. o., 2016). | - Manitoba uses a 2 - zone concept but it is founded more in the type of flood protection that can be used.<br>- The floodway fringe is defined as the area which, if removed from the active flow zone, would raise the water level by less than 0.3 m.<br><br>-The design event for critical infrastructure, such as the City of Winnipeg, is the event that can be justified through a benefit cost analysis. It is currently the 1:700 year event for Winnipeg.<br><br>- There is some talk about including some aspect of climate change, but our flooding is so widespread that we haven't caught up with current requirements, so not yet. | 0.05 mg/l (rivers) and 0.025 mg/L (lakes) | Below 200 E. coli per 100 mL recreational activities are considered safe (Manitoba Sustainable Development, 2016) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | 2.9 mg/L | 120 mg/L | The province sets out guidelines to provide owners with the direction to develop forest management plans to adhere to Manitoba's commitment to sustainable development taking an ecosystem approach. The guidelines provide a 20 year framework (Government of Manitoba, 2007). |
| Saskatchewan | The province has an association of watersheds as an umbrella organization for watershed associations which are formed by watershed stewardship groups to develop watershed plans (CCME, 2016) | The province provides a guide that outlines the principles for watershed planning, the steps of the planning process, structure of the watershed plan, implementation process and identifies priority areas (SWA, 2002). | Development be prohibited in the floodway of the 1:500 year flood elevation of any watercourse or water body and that new development in the flood fringe of a 1:500 year flood be flood proofed to an elevation 0.5 metres above the 1:500 year flood elevation (Government of Saskatchewan, 2016b). | 0.05 mg/l | Geometric mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | - | 120 mg/L | Forest companies are required to acquire licenses if they have forest resources in their area and are also required to prepare long-term management plans. As companies put their plans into practice, they report on their progress to the public through annual reports. The ministry also evaluates the company's performance and compliance (Government of Saskatchewan, 2016). |
| Alberta | The province has established watershed planning and advisory councils to provide funding and support state of watershed reports and integrated watershed management plans (CCME, 2016). | Guidance document on Watershed Management Planning that outlines an iterative process of adaptive management from planning to implementation to evaluation and back to planning in efforts to identify and address priorities issues and opportunities within a watershed (Alberta, 2015).<br><br>Southern Alberta developed a guide on Indicators for assessment environmental performance of watersheds. The environmental indicators to be identified are for land, water quantity, water quality, and aquatic and riparian ecosystem health. For each of the indicators, the guide summarizes the need for potential or existing targets and thresholds (Coombs, 2008). | 1. Two zone approach<br>2. Not defined by rainfall here; rather 1:100 year average recurrence interval (ARI) flood discharge or same ARI ice induced water level.<br>3. Climate change is considered but documentation provided to date points to no statistical evidence of change. | 0.05 mg/L | Geometric mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | - | 120 mg/L | The Alberta Forest Management Planning Standard directs how to prepare and implement forest management plans as directed under the provincial forest management agreement. Alberta has Fire Smart Management which integrates fire, forest and land management planning activities attaining sustainable forest management. Certification is recommended but not enforced (Government of Alberta, 2006). |

| Province | Status on Integrated Watershed Management | Watershed Planning Guidance | Floodplain Management | Freshwater Quality(ECCC, 2016)(Environment Canada, 2015) | | | | | Forest Cover |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total Phosphorus | E. Coli | Benthic Macroinvertebrates | Nitrate-Nitrogen | Dissolved Chloride | |
| British Columbia | The province has not defined a specific structure or planning approach but includes strategic planning with forestry and watershed management elements (CCME, 2016). | The province provides very general guidance on watershed management and planning. There are no set targets for in stream requirements (WCEL, 2011). | - 200-year flood to define the flood risk area, but divides it into two zones, the floodway, where further development is discouraged, and the flood fringe where flood proofed development is possible.<br>-Metro Vancouver is in the midst of developing a new WWTP at Lion's Gate. The flood assessment to establish the Flood Construction Level (FCL) did incorporate the potential for climate change to influence SLR, storm surge and rainfall. | 0.025 mg/L | Specific water quality criteria for specific water use. For example, less than or equal to 77/100 mL geometric mean for recreational use with primary contact. (Ministry of Environment and Parks, 2001) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | 2.93 mg/L | 120 mg/L | There are Provincial Timber Management Goals and Objectives guidelines which sets out the goals, objectives and targets that address changing forest conditions, climate changing etc. The guideline sets out timber management goals and objectives as well as provincial and local targets and strategies to meet those targets (MFLNRO, 2014). |
| Yukon | Does not have a watershed based approach or any specific integrated watershed management planning or approach (CCME, 2016) | The province has developed a guide on Yukon's Peel Watershed Ecosystems. The plan provides a guide to ecosystem mapping which can be used for other watersheds. No set guidelines have been provided for in-stream requirements/ targets (Meikle & Waterreus, 2008). | | 0.025 mg/L | mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | Nitrate total dissolved 2.93 mg N/L Nitrite total 0.02 mg N/L Nitrogen dissolved 0.7 mg N/L | - | 3 Levels of Yukon Forest Planning: 1) Forest Resources Management Plans - provides broad direction on where and why forest resource management activities should take place, 2) Timber Harvest Plans - identifies strategies for reducing or eliminating environmental consequences and impacts on other resources identified in the forest resources management plans, and 3) Site Plans - identifies stand level management activities, methods, and standards for harvesting to ensure the protection of the forest resource values on that harvest area (Government of the Yukon Territory, 2016). |
| Northwest Territories | No formal watershed committees have yet been established (CCME, 2016). | The province has put forth a water stewardship strategy action plan for 2016-2020 which outlines the development of appropriate indicators for ecological integrity for freshwater ecosystems with thresholds and targets with respect to water quality, sewage works etc. (Government of the Northwest Territories, 2016). | | Lentic-lotic sites: 0.03 mg/L Lotic sites: Site Specific Guidelines (mean + 2 standard deviations) | mean concentration (minimum of five samples for primary contact recreational use): ≤ 200 E. coli/100 mL (Health Canada, 2012) | Canadian Aquatic Biomonitoring Network (CABIN) is the national biomonitoring program coordinated by Environment Canada to provide a standardized sampling protocol for assessing aquatic ecosystem conditions | Lentic-lotic sites: 2.93 mg N/L Lotic sites: : Site Specific Guidelines (mean + 2 standard deviations) | Lentic-lotic sites: 120 mg/L Lotic sites: Site Specific Guidelines (mean + 2 standard deviations) | NWT have a commercial timber harvest planning and operations standard operating procedures manual. Tue purpose of the manual is to promote best practices by presenting standards for sustainable forest management. The manual is just guidelines but can be enforced only under licenses and permits (ENR, 2005). |

# Appendix B State of Infrastructure Adaptation

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**Table B-1 Current Climate Change Adaptation Strategies/Action Plans in Provinces and Territories**

(Source: Pan-Canadian Framework on Climate Change, 2016)

| Province | Plan/Strategy | Actions |
|---|---|---|
| Ontario | Ontario's Climate Change Strategy 2015 | • Integrate climate change adaptation considerations into infrastructure decision-making;<br>• Align climate change objectives with agriculture and natural systems; and establish a climate change modeling collaborative for climate data. |
| | Ontario Five Year Climate Change Action Plan 2016-2020 | • Update environmental assessments to ensure that projects are prepared for future changes to climate; and<br>• Consult and propose amendments to the Planning Act to make climate change mitigation and adaptation mandatory in municipal official plans. |
| Quebec | 2013-2020 Government Strategy for Climate Change Adaptation | • Integrate climate change adaptation into the public administration;<br>• Develop knowledge and know-how;<br>• Build awareness and provide training;<br>• Modify land use and manage risks to reduce vulnerabilities;<br>• Maintain the health of individuals and communities;<br>• Preserve economic prosperity;<br>• Improve the safety and longevity of buildings and infrastructure; and<br>• Conserve biodiversity and the benefits of ecosystems. |
| | Climate Change Action Plan 2013-2020 | • Maintain the 2008 Climate Change Strategy's goals to give priority to initiatives centered on the enhancement of air quality, the prevention of heatwaves and heat islands;<br>• Give guidance to the economic players most vulnerable to the effects of climate change;<br>• Document and anticipate changes to important Québec industry, including forestry, agriculture, mining and tourism;<br>• Continue to conduct research and assessments on the durability and safety of infrastructure;<br>• Update biodiversity and ecosystem evaluation, protection and management tools; and<br>• Update knowledge and adapt water resource management tools. |
| New Brunswick | Climate Change Action Plan 2014-2020 | • Incorporate climate change adaptation into decision making;<br>• Examine existing funding arrangements to identify ways to encourage the preparation and implementation of local climate change adaptation plans;<br>• Work with communities to evaluate vulnerabilities of municipal infrastructure and help ensure that facilities are resilient to climate change impacts;<br>• Mainstream adaptation by incorporating it into every day decisions; and<br>• Reform dyke land management and related legislation to address the risk posed by climate change. |

| Province | Plan/Strategy | Actions |
|---|---|---|
| Nova Scotia | Towards a Greener Future: Nova Scotia's Climate Change Action Plan 2009 | • Create an Adaptation Fund within Nova Scotia Environment to encourage adaptation research and development;<br>• Incorporate climate change impacts and adaptation response plans into the strategies and initiatives of all provincial departments by 2012;<br>• Launch a web-based clearinghouse of information and tools to support adaptation to climate change in Nova Scotia in 2009;<br>• Begin work on a biannually-updated provincial vulnerability assessment and progress report;<br>• Create an interdepartmental steering committee and external advisory committee for coordinating adaptation efforts and providing adaptation policy advice;<br>• Take sea-level rise into consideration and place priority on conserving coastal wetlands in preparing a policy to prevent net loss of wetlands; and<br>• Release a Sustainable Coastal Development Strategy to strengthen the province's resilience to climate change impacts on the coast. |
| Prince Edward Island | Prince Edward Island and Climate Change—A Strategy for Reducing the Impacts of Global Warming 2008 | • Create an interdepartmental working group to identify and manage current and projected climate-related risk;<br>• Encourage sustainable options for future land developments;<br>• Incorporate climate change outcomes into the environmental impact assessment process; and<br>• Support a collaborative regional effort for catastrophe planning, coastal erosion sensitivity mapping, and increased salt water intrusion into aquifers. |
| Atlantic Region | Climate Change Adaptation Strategy for Atlantic Canada 2008 | • Take a centralized approach to addressing common and unique risks, vulnerabilities and opportunities in the Atlantic region;<br>• Provide direction on matters of regional interest related to the integration of climate change adaptation considerations in decision-making;<br>• Take a strategic approach through which the Atlantic region can climate-proof development decisions while recognizing unique provincial situations;<br>• Integrate principles of sustainable development, facilitating social progress (social equity), a clean and healthy environment (environmental quality) and economic growth (economic viability);<br>• Collaborate with professional associations, such as engineers and planners, and the public and private sectors;<br>• Engage other stakeholder networks;<br>• Enhance the resilience and adaptive capacity of Atlantic Canada public and private sectors to climate change;<br>• Conduct a gap analysis for risk and vulnerability assessments, including infrastructure;<br>• Improve the relevance and usability of information on impacts of climate variability and climate change, so that it can be used appropriately by development practitioners;<br>• Develop and apply appropriate tools to address climate risks in development activities and to prioritize responses;<br>• Promote an understanding of climate change and its impacts within the private sector, government departments, agencies and local governments in collaboration with professional partners; |

| Province | Plan/Strategy | Actions |
|---|---|---|
| | | • Identify and use appropriate entry points for integrating adaptation to climate variability and climate change into development activities;<br>• Identify and prioritize adaptation responses and, where necessary, help integrate such considerations within a wide range of sectoral interventions and projects;<br>• Periodically assess progress on integration of climate risks and adaptation in development activities and efforts to strengthen adaptive capacities; and<br>• Establish through a Memorandum of Understanding, under the Council of Atlantic Environment Ministers, a commitment to collaborate on adaptation and formalizing the Climate Change Adaptation Strategy for Atlantic Canada. |
| Yukon | Yukon Government Climate Change Action Plan 2009 | • Consider the impacts of climate change when planning and maintaining infrastructure to ensure it is safe, usable, and fiscally responsible;<br>• Experiment with road-building techniques to reduce permafrost degradation;<br>• Complete a Yukon infrastructure risk and vulnerability assessment and determine adaptation strategies needed in response;<br>• Develop an inventory of permafrost information;<br>• Continue to monitor the impacts of climate change on water and complete a Yukon water resources risk and vulnerability assessment;<br>• Conduct a Yukon forest health risk assessment;<br>• Conduct treatments to reduce forest fuel loads and protect communities;<br>• Understand how biodiversity is threatened by climate change;<br>• Continue to participate in land-use planning to ensure the implications of climate change are considered and incorporated;<br>• Monitor human health trends, evaluate health programs and keep services responsive to changing priorities and demand; and<br>• Continue to work proactively to identify potential, new or expanded threats or events that might be the result of climate change. |
| Northwest Territories | A Greenhouse Gas Strategy 2011-2015 | • Determine the vulnerability of infrastructure to climate change using risk management protocols;<br>• Consider climate change adaptation in building guides to provide best practices for changing snow loads and foundations on permafrost;<br>• Evaluate new technologies like thermosiphons to maintain permafrost under foundations;<br>• Increase monitoring;<br>• Predict changes in forest ecosystems;<br>• Establish a NWT climate change adaptation committee composed of representatives from departments to coordinate adaptation initiatives across government;<br>• Fund workshops on climate change adaptation and regional climate change;<br>• Provide funding for community adaptation plans;<br>• Research landscape disturbance and hydrology; and<br>• Share knowledge and best practices with Nunavut and the Yukon through the Pan-Territorial Adaptation Strategy from 2011. |

| Province | Plan/Strategy | Actions |
|---|---|---|
| | | |
| Nunavut | Upagiaqtavut: Climate Change Impacts and Adaptation in Nunavut 2011 | • Ensure climate change considerations are integrated into land use planning and environmental assessments;<br>• Identify new economic opportunities associated with climate change; and<br>• Work with partners to ensure climate change impacts are considered in emergency planning. |
| All territories | Pan-Territorial Adaptation Strategy 2011 | • Secure effective funding and program partnerships with the federal government for climate change adaptation initiatives and continue to fund programs and initiatives from territorial government resources;<br>• Establish a formal network of climate change officials in the governments of Yukon, Nunavut and NWT to support collaboration;<br>• Continue to build and strengthen partnerships between and among local, territorial, federal and Aboriginal governments;<br>• Look to other circumpolar countries for partnerships and best practices;<br>• Continue to support community efforts in improving resilience to climate change;<br>• Assist communities to acquire funding and resources needed for effective adaptation;<br>• Integrate climate change considerations into policy, construction practices, and natural resource stewardship;<br>• Increase public awareness of the effects of climate change and the importance of adaptation;<br>• Promote the sharing of knowledge from adaptation research;<br>• Host climate change adaptation workshops every two years;<br>• Continue and expand monitoring and data collection;<br>• Improve access to projections of future local climate change scenarios;<br>• Support efforts by partners to secure investment in climate change adaptation research and development; and<br>• Encourage investment in and development of adaptation technologies to protect water systems, infrastructure, search and rescue management and traditional economies and culture. |

## Table B-2 Water Infrastructure (Stormwater) State of Adaptation Measures

| Climate Parameter | Impact | Interaction with Watershed/ Economics/Social Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (STORMWATER) | | | | | | | |
| Short Duration High Intensity (SDHI) Rainfall Events | URBAN AND RIVERINE FLOODING<br>Stormwater Conveyance<br>- Urban areas built prior to flood control standards (typically prior to 1970s) are more vulnerable to extreme rainfall as roads were not designed to convey large events away from urban areas.<br>- Current Standards are not designed to handle the future SDHI as the infrastructure sizing and IDF curves reflect historic data. Stormwater conveyance systems can be easily overwhelmed due to insufficient capacity (e.g., 100-150 mm in Burlington, 2014, 225 mm in Nova Scotia, 2016)<br>- Reduced efficiency of aged stormwater pipes resulting in inadequate conveyance and leakage. More stormwater is generated in areas with low infiltration soils with seasonally high water table. | - In-stream Erosion which can undermine culverts, damage roadways, and/or transit tracks<br>- Sanitary back-up due to stormwater inflow and infiltration into the systems<br>- Wastewater treatment plant by-pass due to stormwater inflow and infiltration into the system<br>- Degradation of water quality which may impact drinking water supply, recreation, and aquatic life. | - Update IDF curves and sewer design standards to reflect future climate conditions<br>- Increase infrastructure capacity for new and reconstruction to reflect revised design standards (e.g., increase size of sewers and culverts)<br>- Set basements elevations for new construction a minimum amount (e.g., 1 m) above the sewer obvert.<br>- Increased inspection of stormwater infrastructure such as pipes, culverts, and outfalls.<br>- Province of Newfoundland and Labrador has updated IDF curves based on climate change impacts.<br>- City of London has updated IDF curves by 21% (but has not applied updated curves yet).<br>- City of Moncton in New Brunswick introduced a 20% allowance in the historical data of 1 in 100 year storm- major stormwater system.<br>- City of Ottawa is requiring stress test on all drainage systems using design storms calculated on the basis of a 20% increase of the City's IDF curve rainfall values/100 year storm event. Modifications to the drainage system will be required if severe flooding is identified (Lafleur, 2015). | - Municipalities are updating IDF curves (e.g., City of Barrie increased IDF curves by 15% to account for climate change, based on literature review)<br>- 75% municipalities surveyed (Frontlines of the Flood study) have upgraded infrastructure based on vulnerability assessment priorities<br>- To adapt and build capacity, communities of Cambridge and Milton, ON, completed an economic impacts assessment of climate change scenarios. City of Cambridge increased conveyance infrastructure capacity to 1:500 year and providing designated flood storage. Town of Milton completed a complex hydrologic model considering current and future climate change scenarios to ensure capacity (Scheckenberger et al, 2009).<br>- Economic impacts assessment study also recommended that municipalities complete an assessment of the economic impacts of larger drainage infrastructure designed to less frequent design storms i.e.: 250-500 yr. to assist local municipal decision makers in managing risk (Scheckenberger et al, 2009).<br>- Investigate and apply meteorological changes based on global climate models to a hydrologic model using a continuous time series to look at a more comprehensive response function to speculate climate change impacts when managing stormwater to provide flood control (Scheckenberger et al, 2009).<br>- PEI has updated IDF curves that account for climate change and will be used for all new development | - Current design storms being used to size major and minor systems as the rainfall distribution may not be reflective of SDHI. IDF curve method may not be appropriate for areas experiencing severe isolated storms.<br>- Lack of clear direction from federal and provincial governments on how to update design standard to ensure new development is resilient (fear that development industry may challenge municipality if they have unique climate change standards). A review was completed of Ontario regulations and legislations in light of climate change and it was concluded that even though climate change is alluded to, there is no clear guidance on how it shall be incorporated in the regulations (Zizzo & Kyriazis, 2015).<br>- Hesitance to update codes and standards due to added costs of meeting a higher standard. | - Methods and tools to update IDF Curves (e.g., IDFCC Tool, Ontario Climate Change Data Portal)<br>- Accessible climate data sources including maps, data, graphs of future climate conditions (e.g., Canadian Climate Change Scenarios Network, the Pacific Climate Impacts Consortium, Ouranos)<br>- Financial tools to fund the additional cost associated with the increased infrastructure capacity (e.g., stormwater rates)<br>- Increase the magnitude of design parameters or safety factors | - Unified approach to updating IDF curves and design standards (i.e., direction from provincial/federal government)<br>- Increased funding for municipalities to increase capacity of infrastructure to account for future climate conditions.<br>- Need goal oriented approach as opposed to prescriptive approach for infrastructure sizing. In some cases SDHI events experienced locally would create a bigger floodplain as opposed to Hurricane Hazel. |
| | URBAN AND RIVERINE FLOODING<br><br>Stormwater Controls<br>- Urban areas built prior to floodplain management are more susceptible to riverine flooding as they lack any | | - Modeling tools that predict flooding due to storm sewer surcharging<br>- Model historic and future climate scenarios, local SDHI and hurricane scenarios to | - Currently there are no standards or regulations for Stormwater sizing or treatment requirements. Little guidance on how to determine a sufficient level of service within an urban area. | - Lack of qualified professionals to design, construct, and maintain low impact development/new technologies.<br>- Lack of information to support asset management planning for stormwater ponds and LID measures | - Providing educational workshops/programs<br>- Organizations such as Canadian Institute of Planners, Canadian Water and Wastewater Association and Water | - Provide funding mechanism for capital and operations.<br>- Need for integration of planning, capital works, and emergency services to optimize water infrastructure investment and |

| Climate Parameter | Impact | Interaction with Watershed/ Economics/Social Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (STORMWATER) | | | | | | | |
| | controls to reduce increased flows from urbanization.<br>- Urban areas built post 1970s are built to maintain predevelopment peak flows based on historic rainfall data. SDHI may overwhelm the system producing a larger floodplain (more dwellings at risk in the SDHI floodplain compared to historical floodplain).<br>- Full stream banks cause the outfall from the storm sewers to back-up into the system causing urban flooding. | | develop floodplain mapping to reduce risk of dwellings in the floodplain.<br>- Flood risk Canada's live flood sensory system deployed in floodways allows property owners to access data online from any location and monitor it live and set alerts for when flood barrier deployment is needed. The system monitors streams and rivers, measuring wave action, tires, currents, stream levels, streamflow data, groundwater levels, amount of rainfall, wind speed and dam failure (Canadian Underwriter, 2016). This tool should be further investigated and applied with caution. | - Many municipalities have strategies/plans to conserve water. The City of Calgary has set a goal to increase water-use efficiency, and thus reduce demands on the water system, by 30 percent over 30 years so that they can accommodate future growth while maintaining the amount of water removed from the river at 2003 levels. | - Fear of knowing infrastructure risks and liability associated with those risk and potential for litigation if municipality lacks financial resources to invest in upgrades.<br>- Prescriptive Guidance and regulations may be preventing local based adaptation (i.e. In Ontario, hurricane hazel may produce a smaller floodplain than a SDHI event, lack of flexibility in guidelines to make locally informed decisions, guideline updates take too long for adaptive management,<br>- Current regulations are unclear as to how to address spillways. | Environment Association of Ontario have introduced Climate Change and Adaptation programs as a continuous professional learning to their members.<br>- Mandatory downspout disconnection<br>- Provide insurance incentives for backwater valves<br>- Toronto basement flood protection program designed to address stormwater management, infiltration/inflow and lot-level controls. Similar programs have been initiated in Edmonton, Montreal and Moncton. | reduce risks to vulnerable populations.<br>- Need for sustainable funding mechanism to support WI upgrades<br>- Goal oriented policies/standards are needed for local decision making.<br>- Jurisdictions and departments need to integrate and adopt LID in existing urban areas and new development and infill areas to maintain predevelopment hydrology to optimize water infrastructure.<br>- Develop a regulatory framework/protocol that allows municipalities to deal with unacceptable infiltration/inflow in new subdivisions. The framework will allow municipalities to reduce the assumption of poorly designed and performing sanitary sewers and get them fixed (Robinson et al, 2016). |
| | URBAN AND RIVERINE FLOODING<br><br><u>Stormwater Management Ponds</u><br>- Stormwater systems are typically not designed to maintain pre-development runoff volume. When watersheds urbanize increased paved surfaces translates to more runoff volume as there is less ability to infiltrate into the ground. Stormwater ponds are designed to slow down the flow to the stream but more runoff volume enters the stream causing stream banks to become full more frequently and for longer duration than predevelopment.<br><br>- Streamflow monitoring has found despite stormwater ponds, wet weather stream flows can be as much as 3 times higher due to higher runoff volume and coincidental peaks from multiple ponds increasing the risk of riverine flooding and the floodplain. | | - Implement additional source/lot level and conveyance control (e.g., low impact development on public and private property disconnecting downspouts, backwater valves)<br>- Implement site control measures in new developments to ensure sufficient capacity | - Municipalities are demonstrating the implementation LID measures to control SW, but on a small scale | - Lack of public and political will to implement new technology (e.g., green infrastructure).<br>- Lack of funding for additional stormwater controls and road retrofits i.e.: low impact development. For example, the roads in Mississauga, ON when put end to end can go from Newfoundland and Labrador to British Columbia. 20% road retrofits would provide climate change resiliency.<br>- Non-related regulations such as Development Charges Act or Building Code may be impeding municipalities from making science based decisions.<br>- Inadequate consideration of extreme rain events and infiltration/inflow reduction in plumbing and building code. For example, no requirement for power backup systems for sumps, limited guidance for sump and pump capacity leading, no requirement for downspout extensions, etc. | - Incentives to increase stormwater control on private property (e.g., rain barrels, downspout disconnection, sump pump rebates, reduced impervious cover)<br>- Identify locations that may be vulnerable to climate change impacts and avoid them altogether or modify designs accordingly<br>- - Low impact development Guidance: CVC Low Impact Development Road Retrofits Guide, CVC Low Impact Development Business and Multi-Residential Retrofit Guide, CVC Low Impact Development Public Lands Retrofits Guide, CVC Low Impact Development Residential Retrofits Guide, CVC and TRCA Low Impact Development Design Guide, CVC Low Impact Development Construction Guide, CVC and TRCA Landscape Design Guide for Low Impact Development and CVC | - Include climate change and adaptation in professional training and education programs (e.g., design of Green Infrastructure as part of water resources engineering training).<br>- Review mechanisms to include stormwater and the increased footprint should require more lot-level controls.<br>- Municipalities need to consider developing new bylaws or updating existing bylaws to incorporate increased footprint size and the need for increased SWM.<br>- Address extreme rainfall risk, infiltration/inflow issues for greenfield and infill development in national and provincial construction codes.<br>- Improved understanding of the root causes of excess infiltration/inflow in new and existing subdivision. |

| Climate Parameter | Impact | Interaction with Watershed/ Economics/Social Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (STORMWATER) | | | | | | | |
| | | | | | | Low Impact Development Certification Protocols: Bio-retention Practices.<br>- Various municipal Infiltration/ Inflow and flood protection education and subsidy programs with varying degrees of success across the country. | |
| | - No maintenance of stormwater management ponds increase risk of urban and riverine flooding | | | - Lake Simcoe Region Conservation Authority study found that half of 98 ponds surveyed were not meeting MOECC permit design level of service (LSRCA, 2011).<br>- In Canada there is an increasing trend in litigation against municipalities (i.e.: City of Stratford, City of Thunderbay, and City of Mississauga) as a result of urban and riverine flooding (Zizzo et al, 2014). Class action suits primarily fell into two categories, failure to maintain stormwater management system, failure to enforce by-laws. | - Limited funding to support maintenance and enforcement as municipalities receive some funding for capital works projects (typically 1/3 split between municipal, provincial, federal government). | - Financial tools/resources for e.g.: stormwater rate, taxation, dedicated federal/provincial funding | - Need improved policies, regulatory and financial tools to enable the integration of climate change adaptive considerations into infrastructure decision-making, design and maintenance.<br>- Municipalities need to define a risk tolerance (i.e., want to control 100 year floods now and/or 75 years into the future) and ensure that the goal is met throughout the life of the infrastructure. |
| | RIVERINE FLOOD RESPONSE AND WARNING<br>- Difficult to predict in advance, posing a challenge in terms of warning and emergency response. Especially in older urban areas where floodplain management was not enforced and/or older areas have no floodplain management in place including many areas built prior to 1970s,hence no opportunity to regulate development. More structures and buildings maybe vulnerable to riverine flooding.<br><br>-Current standards use historic rainfall to determine floodplain mapping recent SDHI events produced larger floodplains than historic data.<br>- Metrological analyses (e.g., Paixao et al, 2011) that municipalities will experience localized, warm season extreme rainfall events, although spatial patterns exist for seasonal and annual precipitation. | - Varying precipitation patterns impact seasonal streamflow and base flows.<br>- localized extreme events contribute to riverine flooding events<br>- Increased risk of property damage, loss of life as SDHI events may produce larger floodplains than historic events (more dwellings in the SDHI floodplain).<br>- City of Toronto and Toronto Region Conservation Authority has completed a flood-vulnerable map that shows structures at risk of flooding as they were built prior to floodplain policies (Cain, 2013). SDHI storms can increase the risk of flooding of such structures. | - Emergency response plans created by municipalities<br>-Flood warning systems<br>-Flood forecasting using weather forecast<br>-Continuous streamflow monitoring to predict riverine flooding incidents<br>- Model historic and future climate scenarios, local SDHI and hurricane scenarios to develop floodplain mapping to reduce risk of dwellings in the floodplain | - Emergency plans exist for flooding but they do not always address SDHI events as expected with climate change (they mainly address hurricane events with lots warning in place). | - Lack of resources such as local data/information<br>- Lack of trust in science<br>- Lack of connection between staff completing emergency plans and climate change science<br>- Lack of sufficient training for emergency staff because extreme weather and associated hazards can also prevent workers who operate water infrastructure from accessing facilities. | - Climate change tools and models<br>- Groups like Canadian Climate Change Scenarios Network, the Pacific Climate Impacts Consortium, and Ouranos are providing access to relevant and useable data, maps and graphs of future climate conditions.<br>- Calgary has addressed this risk by implementing cross-training programs to ensure that trained staff/system operators are available at all times (Associated Engineering, 2011).<br>- Risk assessment and risk management tools (e.g., PIEVC etc.). | - Develop a one-window central for climate data and climate change models<br>- Develop localized climate projections<br>- Develop better informed emergency management plans for infrastructure failures or extreme weather emergencies. For e.g.: municipalities in the US jurisdictions have tornado warning programs to educate residents. Consider how they may be adopted to reduce risk for residents, especially vulnerable populations within the floodplain.<br>- Need for guidance on how to interpret existing information and understand uncertainty in climate change projections. Professionals need to be trained to use the most appropriate future scenarios based on local risks as no single projection will fit. |
| | RIVERINE FLOODING<br>- Passing accumulated debris into the system resulting in blockage of flow to culverts and catch basins, which in turn can result in localized flooding or | - Increased flow in streams/rivers resulting in flooding and erosion in the receiving streams. | - Increase capacity of crossings/upsizing of culverts to better handle intense events.<br>- Better operations | - Following the Finch avenue culvert washout due to lack of maintenance. City of Toronto has increased monitoring and maintenance of its culvert systems. | - Lack of resources such as local data/information<br>- Lack of resources such as staff to perform frequent/regular maintenance on infrastructure | - Increase the magnitude of design parameters or safety factors<br>- Prioritize asset retrofits by identifying infrastructure at risk | - Develop and standardize stormwater quality management standards to keep a constant check on operations and continuously make improvements as needed. |

| Climate Parameter | Impact | Interaction with Watershed/ Economics/Social Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (STORMWATER) | | | | | | | |
| | erosion in surrounding areas, damaging the physical infrastructure.<br>- Insufficient maintenance of critical stormwater infrastructure | | management through frequent debris removal (e.g.: regular maintenance of pipes, culvert cleaning, street sweeping, and forest debris management). | | | | - Integrated asset management plans (operations and maintenance)<br>- Use an increased deterioration rate in design and maintenance plans |
| | Groundwater (Chu, et al., 2016)<br>- SDHI type events coupled with urbanization introduce new sources of recharge. These sources are usually unaccounted for and include infiltration from septic systems, leaking sewers and water mains, excessive urban irrigation, naturally occurring stormwater runoff or intentional runoff as a result of stormwater management techniques i.e.: LID/GI.<br>- Excess recharge results in rising groundwater and an upward flushing of salts and contaminants that had previously accumulated in the shallow unsaturated zone.<br>- Rising groundwater levels can cause flooding of streets, cellars, sewers, septic systems, utility ducts, and transport tunnels; reduce the bearing capacity of structures; and affect amenity space by water-logging sports fields and killing trees. | - Reduced water quality in areas where groundwater directly discharges into streams/rivers introducing salts and contaminants. | - One example of groundwater protection is for the Calgary Zoo, which suffered $25 M loss due to overland, and groundwater flooding. One of the recommendations to be implemented include the sealing of the island from groundwater with sheet or secant pile walls (secant piles are drilled shafts constructed in such a way that the shafts overlap each other to form a wall) and installing a pumping system to dewater the grounds following extreme rainfall resulting in seepage and stormwater runoff incidences (Barrett, 2014). | - Currently, no adaptation examples were presented that specifically addresses groundwater flooding. This has been defined as an area for further research. | - Lack of knowledge as groundwater flooding is under-researched and often under-recognized for its role in flooding (McGillivray, 2014). | - No existing tools/practices were presented to address groundwater flooding. However, recommendations are made to better understand the relationship between groundwater, surface water and flood water. There is also need to improve groundwater management and knowledge for future flood preparedness and mitigation measures (Alberta Water Portal, 2013). | - A network of monitoring wells to measure groundwater. Overland flood routes are known and can be coupled with groundwater level monitoring to define potential groundwater flooding areas.<br>- Regulating the height of basement floors relative to the height of the aquifer via construction codes and bylaws.(McGillivray, 2014).<br>- Further research is required to expand knowledge groundwater and flooding especially for rebuilding and future building areas so the risk of rising ground water may be taken into account and resulting flooding be mitigated (Hugo, 2015). |

## Table B-3 Water Infrastructure (Drinking Water) State of Adaptation Measures

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (DRINKING WATER) | | | | | | | |
| Short Duration High Intensity Rainfall Events | - Flooding of the water treatment plant (WTP) can result in no access and power outage at the plant (Genivar, 2007).<br><br>- As a result of 2013 Alberta Flood, McLean Creek Campground Waterworks System – Kananaskis lost power and was unable to produce water (Alberta, 2013). | - Can potentially pose a chemical spill hazard into the receiving waters i.e.: potassium permanganate. | - Flood proofing of electrical panels and ensuring adequate backup power<br>- Implement mitigation measures such as elevating electrical equipment and having emergency generators in place (USEPA, 2014). | - Emergency management plans in place but do not account for short duration high intensity storm events as they are difficult to predict. | - Lack of sufficient training for emergency staff because extreme events and associated floods can prevent workers from operating or accessing treatment facilities | - Drinking Water Quality management Standards | - Develop a standard for water treatment plant flood proofing standards taking into account climate change risks. This is not being done currently but is a potential opportunity to explore further in building resilient treatment facilities. |
| | Flooding of the water treatment plant can pose a risk to stored treatment chemicals/materials (Genivar, 2007) resulting in a water quality issue. Inadequacies can result in treatment plant shut down | | - Best management practices and risk management plans are in place as means of spill prevention/contingency plans for petroleum tank farms near Intake Protection Zone – 3 (floodplain) (CTC Source Protection Region, 2015).<br>- Flood proofing of water treatment plants through construction of physical barriers between treatment plants and nearby water bodies.<br>- Provide upstream treatment measures that accommodate the increase in treatment requirements following an extreme rain event such as green infrastructure/LID.<br>- Municipalities should review their flood protection plans related to each bulk chemical/hazardous material and develop an action plan in case of flooding. | Source water protection introduces various tools to manage land uses and gives municipalities the responsibility and authority to regulate activities that may pose a risk of contaminating drinking water sources (drinking water threats) on a site-specific basis. Individual municipalities have defined water intake protection zones and wellhead protection zones.<br>- Environment and Climate Change Canada has delegated emergency pollution incident response programs to federal/provincial authorities. Each province/territory has a 24 hour telephone number for notification and response initiation. For example in Ontario, the Ministry of the Environment and Climate Change and the Spills Action Centre coordinate spills response.<br>- Implement mitigation measures such as bolting down chemical tanks (USEPA, 2014).<br>- Vulnerabilities to chemical and hazardous materials storage can be related to floods, ice jams, intense winds and tornadoes. | - No knowledge gaps or barriers have been identified in this area. | - Real-time spills monitoring in the creek for water quality is being used to receive early warnings and administer appropriate clean up response and avoid further damage to infrastructure and the ecosystem.<br>- Capacity reserve is considered a climate adaptation strategy. Capacity reserve can be put into effect in case of a sewer overflow or a chemical spill, in aftermath of an extreme event causing flooding, or during inadequate capacity to increase chemical feeds (Levine et al, 2016). | - Opportunity to further investigate and develop standards for climate resilient chemical/materials storage.<br>- Can be achieved through drinking water quality management standards. Climate change and variable precipitation should be accounted for in determining chemical reserve capacities to ensure resilience. |
| | - Vulnerability to conveyance erosion exposing and breaking water mains in proximity to streams. | - Results in more erosion of the natural stream and result in contaminated potable water spill. | - increased erosion monitoring in erosion prone streams/rivers<br>- build erosion modelling capacity to incorporate climate change affects<br>- Pipeline integrity monitoring is required.<br>- flow monitoring in rivers/streams | - 3 yr. Atlantic stormwater initiative to support the design and installation demonstration sites to better manage water quantity, flows, quality (Clean Nova Scotia, 2016). | - Lack of funding<br>- Lack of resources i.e.: experienced personnel to properly design and construction low impact development practices. | - Build erosion models to account for climate change affects in erosion prone areas.<br>- Low impact development Guidance: CVC Low Impact Development Road Retrofits Guide, CVC Low Impact Development Business and Multi-Residential Retrofit Guide, CVC Low Impact Development Public Lands Retrofits Guide, CVC Low Impact Development | - Incentivize source controls to mitigate downstream erosion impacts |

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (DRINKING WATER) | | | | | | | |
| | | | | | | Residential Retrofits Guide, CVC and TRCA Low Impact Development Design Guide, CVC Low Impact Development Construction Guide, CVC and TRCA Landscape Design Guide for Low Impact Development and CVC Low Impact Development Certification Protocols: Bio-retention Practices. | |
| | - For groundwater-dependent communities, SDHI events result in reduced groundwater recharge due to quick conveyance of stormwater runoff. Whereas, under low intensity long duration events, stormwater is able to infiltrate over time or infiltration is promoted through hummocky topography.<br>- All of Prince Edward Island and approximately 90% of the rural population in Ontario, Manitoba and Saskatchewan are groundwater dependant and through previous assessments it has been noted that changes in precipitation patterns may result in a decrease in recharge, particularly in shallow aquifers (Lemmen et al., 2008).<br>- More municipal drinking water systems are at risk due to low water conditions which is becoming more frequent with less recharge because of SDHI events. | | - Implement green infrastructure/LID measures upstream to provide recharge opportunities.<br>- Water conservation to manage groundwater fed areas i.e.: no lawn watering.<br>- Tier 3 studies under source water protection have defined and declared several municipal systems at risk and most associated with decreased groundwater recharge (Well heal protection area – quantity stress (WHPA-Qs) under CTC Source Water Protection) (CTC Source Protection Region, 2015). | - CMHC funding 6 Bio-retention project in cities across Canada e.g.: Ambersand Green Park, Ottawa (CMHC & NRCan, 2013). | - Lack of knowledge/performance data on groundwater contamination from infiltration practices building hesitance to implement. | - Guidance on maintaining water balance through site level controls i.e.: retain 5 mm on site (CVC & TRCA, 2012).<br>- LID performance monitoring to address groundwater contamination concerns through testing for impermeable liner feasibility. | - Standardize groundwater recharge requirements based on site specific needs.<br>- Develop a general groundwater recharge standard to incorporate climate change impacts.<br>- Need best management practices with low impact development/green infrastructure techniques for Issue Contributing Areas (ICAs) as defined under source water protection. |
| Temperatures | - Severe heat dries out the ground causing it to shift (expand/contract) resulting in more water main breaks (CBC News, 2016).<br>- Shallow aquifers (vadose zone) are susceptible to evaporation. Increasing heat days result in lowered water tables increase the risk of formation collapse and sink holes (Perlman, 2016). | - If in proximity of waterbodies, it can result in stream erosion and water quality impacts and retard disinfection resulting in contaminated potable water. | - Municipalities implementing high-tech detection methods to help manage leaky water mains resulting in bursts (Buckler, 2010). | - Spills management through federal/provincial bodies.<br>- Source water protection if in proximity of a drinking water intake and managed through water intake protection zones of wellhead protection zones. | - Knowledge gap around frequency/prediction of freeze/thaw cycles. | - Climate change models can provide a baseline for freeze-thaw cycle expectancies. | - Perform freeze-thaw projections based on climate change models and incorporate into infrastructure design standards (Picketts, 2012).<br>- Municipalities need to implement continuous leak monitoring for areas with a high rate of water main breaks or aged pipe infrastructure through innovative technologies (Echologics, 2016). |
| | - Drinking water pumping stations are also at risk of electrical failure during periods of extreme summer heat due to overheating of building electrical systems (Genivar, 2011). | - No watershed impact. | - Extreme temperatures can affect operations with increased water demand requiring increased flows and pressures resulting in | - Back-up power generators<br>- Adequate cooling mechanisms for equipment<br>- Backup pumps to replace failed pumps or to provide increased pumping capacity due | - No knowledge gaps or barriers identified. | - Harmonized Extreme Heat Warning<br>- Toronto Public Health participated in a pilot Provincial Harmonized Heat Alert and | - Opportunity to coordinate heat alert notifications with operators to be extra cautious and ensure proper cooling measures and back-up power generators are in place. |

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (DRINKING WATER) | | | | | | | |
| | | | increased loads on pumping stations. Continuous monitoring should be in place to identify changes in peak factors (Associated Engineering, 2011).<br>- Extreme temperatures can also affect the physical aspect of pumps resulting in breaker tripping due to extreme heat. Perform ongoing assessments and appropriate corrective actions. Having redundant pumps on stand-by especially engine driven units to maintain operations (Associated Engineering, 2011).<br>During extreme heat events, operators/maintenance crew need to install temporary fans to provide cooling of equipment and ensure function (Associated Engineering, 2011). | to increased water demand in extreme heat days | | Response System (HARS). Extended Heat Warnings are issued if conditions are forecasted to continue for 3 or more days. These heat warnings can be used by water operators to ensure appropriate cooling mechanisms are in place for the heat period. | |
| | - Increased temperature is associated with early algae blooms that can clog drinking water intakes and potential shutdown of the plant.<br>- Growing issue in areas receiving urban and rural runoff which is nutrient enriched. | - Increased temperatures affect the survival of aquatic habitat<br>- Cyanobacteria exposure can affect human health, livestock and pets. Ingestion can cause fever, diarrhea, abdominal pain, nausea and vomiting and external contact can result in irritated and itchy eyes and skin.<br>- More beach closures and recreational use advisories. | - Predict toxic blooms with molecular probes for early warning (Pick, 2016).<br>- In Alberta, effective risk management of harmful algae blooms is being tested for early warning systems. Continuous-imaging cytometry paired with digital imagery is being tested to quickly detect, quantify, and respond to early indicators of potentially toxic cyanobacteria (UoA, 2013). | - Domestic Action Plan to identify programs to measure and achieve targets for Lake Erie through monitoring, modelling, open lake modeling, and tributary modeling. | - Lack of available algal bloom forecasting tools | - Water treatment technologies for nutrient removal i.e.: dissolved phosphorus removal which is a big contributor to algae blooms. Need to implement on a wider scale.<br>- Reduce urban heat island effect. | - Opportunity to incorporate nutrient removal requirements in quality management standards through performance monitoring.<br>- Incentivize implementation of water treatment technologies for nutrient removal. |
| | - Increased temperatures may increase emerging cyanobacteria issue in lakes.<br>- Lake Erie has "toxic algae blooms as a result of naturally occurring cyanobacteria fueled into overdrive due to a combination of warm winter, sunshine and nutrients that come from agricultural runoff, sewage and industry waste" (Maria, 2016). | | The most effective component of a long-term strategy for reducing the incidence of cyanobacterial blooms is to control the input of nutrients (specifically phosphorus and nitrogen) into the water body (Jančula and Maršálek, 2011; Paerl et al., 2011; Matthijs et al., 2012). Conventional filtration, adsorption, chemical | - Alberta Cyanobacteria Beach Monitoring Program<br>- Blue-green algae monitoring in Newfoundland and Labrador<br>- In Europe, real-time monitoring is used to set out warnings. Real-time data through monitoring of parameters such as salinity/temperature that allow for certain bacteria to breed and so when the threshold levels are reached per sensor data, warnings are issued to stay out of the waters. | - Lack of confidence in science due to uncertainties with climate change projections.<br>- Need to investigate real-time monitoring to ensure sufficient warning times versus long waiting time for lab results to arrive and notifications to be given. | - Explore new technologies to build assurance detention and reporting methods | - Ontario municipalities are developing wastewater and stormwater quality management standards. There is opportunity to incorporate in quality management standards through performance monitoring. |

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (DRINKING WATER) | | | | | | | |
| | | | oxidation, activated carbon, biological filtration, membrane filtration and combined treatment technologies and emerging technologies (Government of Canada, 2016e). | | | | |
| | - High temperatures can promote wildfires which can negatively affect the quality of source water, with impacts lasting many years. For example, in the four years after the 2003 Lost Creek fire in Alberta, turbidity, total organic carbon and nitrogen in runoff increased, particularly during peak flows after rainstorms and during spring melt (Emelko et al., 2011). | - Reduce water quality of receiving waters by increasing nutrient concentrations causing chronic conditions for ecosystem health.<br>- Changes hydrological cycle<br>- Adds pollutant enriched stormwater runoff<br>- Increased sediment loading | - Wildfire management programs set by each province in efforts to protect human life and communities first followed by watersheds and infrastructure.<br>- Protect and maintain an adequate supply of drinking water | - Developing emergency assessment of threats to drinking water following Fort McMurray wildfire. Athabasca River provides water supply to 80K people and was contaminated by ash. Exhausting water analysis was performed to take appropriate measures in water treatment process tweaking and understanding downstream impacts (Caldwell, 2016). | - Limited research on after effects of wildfires on a watershed and the degree and time it takes for the ecosystem to recover.<br>- City of Kelowna increased flood capacity/stormwater capacity by increasing the size of culverts to accommodate the increase in water demand and peak flows after the 2003 wildland fire (Wright & Przeczek, 2005). | - real-time water quality monitoring<br>- in stream targets | - need more information |
| | - Increased amounts of chlorine maybe required for water treatment because chlorine decays more quickly in warmer water temperatures. Increased chlorine results in aesthetic issues such as strong odour and taste. | - No watershed impact. | - Chlorine decay modelling in light of climate change with higher temperatures.<br>- Real-time chlorine monitoring | - need more information | - no knowledge gaps or barriers identified | - EPANET with climate change module | - need more information/research required |
| | - Changing ice conditions are also important to consider; for example more periods of frazil ice (accumulation of ice crystals in water) can block intake pipes (Associated Engineering, 2011). | - result in riverine flooding<br>- Dams can malfunction due to flow blockage | Monitor ice cover on rivers/lakes through mapping. | - need more information | - no knowledge gaps or barriers identified | - Synthetic aperture radar (SAR) satellites (Sanden, 2012). | - need more information/research required |
| | - Higher temperatures can result in taste and odour (Associated Engineering, 2011). | - No watershed impact. | - Additional treatment required to reduce taste and odour issues | - WWTP operators adjust treatment based on influent water quality and temperature | - need more information | - need more information | - need more information |
| Drought | - Increased frequency and intensity of heat/dry days results in reduced groundwater table | - Reduced streamflow/baseflow.<br>- Lower assimilative capacity | - Implement green infrastructure/LID measures upstream to provide recharge opportunities. | - Municipalities across Canada are implemented LID/GI to encourage infiltration and less runoff production. | - No regulations for LID implementation despite wealth of guidance documents and performance monitoring results i.e.: International Best Management Practices Database. | - Low impact development Guidance: CVC Low Impact Development Road Retrofits Guide, CVC Low Impact Development Business and Multi-Residential Retrofit Guide, CVC Low Impact Development Public Lands Retrofits Guide, CVC Low Impact Development Residential Retrofits Guide, CVC and TRCA Low Impact Development Design Guide, CVC Low Impact Development Construction Guide, CVC and TRCA Landscape Design Guide for Low Impact Development and CVC Low Impact Development | - Regulate and incentivize LID/GI application for groundwater areas. |

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (DRINKING WATER) | | | | | | | |
| | | | | | | Certification Protocols: Bio-retention Practices, International Best Management Practices Database. | |
| Warm Winters | - Changing climate can affect water availability through seasonal shifts in river flows (e.g. from earlier snowmelt and spring runoff), more intense precipitation events, longer dry spells and more frequent droughts, and lower lake levels (Engineers Canada, 2008).<br>- Low water levels have an implication on drinking water intakes and water supply (MOECC, 2016). | - Altered precipitation patterns, in combination with urban development, can change (and have changed) streamflow regime in natural and urban streams, with higher flows in winter and summer and reduced spring freshet. | - Water conservation and greywater reuse during drier periods to reduce increased water pumping from lakes/rivers.<br>- Great Lakes Management agreements (MOECC, 2016). | - York region water conservation plan (York Region, 2013)<br>- Regina's water conservation program for e.g.: fixed price for water use for the first 28 $m^3$ per household and added fee for every $m^3$ additional (Regina, nd). | - no regulation to enforce water conservation | - Existing water conservation programs implemented by municipalities can be transferable | - Standardize water conservation program guidance |
| | - With higher precipitation totals in winter, and lower precipitation totals in summer months, there is a possibility for increasing municipal water consumption and park maintenance with changing climate. | - Increased water withdrawal during dry summer periods to increased water demand. | - Water conservation and restrictions<br>- Low impact development | - York region water conservation plan (York Region, 2013).<br>- Regina's water conservation program for e.g.: fixed price for water use for the first 28 $m^3$ per household and added fee for every $m^3$ additional (Regina, nd). | - no regulation to enforce water conservation<br>- Better monitoring programs to forecast effects of warm winters. | - Existing water conservation programs implemented by municipalities can be transferable | - Standardize water conservation program guidance |

## Table B-4 Water Infrastructure (Wastewater) State of Adaptation Measures

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (WASTEWATER) | | | | | | | |
| Short Duration High Intensity Events | Sanitary Sewers<br>Sanitary sewers and pumping stations vulnerable to surcharging due to inflow/infiltration of wet weather flows<br><br>Combined Sewer<br>Combined sewers and pumping stations vulnerable to surcharging due to increased volumes of stormwater entering the sewer beyond design capacity. | - Overwhelmed sanitary sewers and combined sewers result in raw or partially treated sewage bypass (CSOs) into the receiving waters severely impact water quality.<br>- Severe ecological impacts in the watershed i.e.: fisheries, as well as recreational use of watershed resources.<br>- Reduced assimilative capacity | - Conduct smoke and/or dye testing to determine locations of inflow/ infiltration<br>- Monitor sanitary sewer flows to determine wet weather flows and locations of inflow /infiltration<br>- Reduce inflow to sanitary sewer due to direct connections (e.g., by disconnecting drains, sump pumps, uncapped cleanouts, and catch basins from the sanitary sewer system)<br>- Reduce infiltration to sanitary sewer system (e.g., by repairing and replacing cracked pipes and joints, relining of pipes, sealing manholes)<br>- Install backwater valves to prevent buildings from flooding during wet weather events where inflow/infiltration issues persist.<br>- Implement low impact development/green infrastructure practices upstream of combined sewer to reduce stormwater volumes entering the combined sewers.<br>-Separation of combined sewer systems<br>-Construction of Combined Sewer Overflow tanks and tunnels to manage wet-weather flows in combined sewer systems | - Municipalities undertaking programs to reduce inflow/infiltration.<br>- Many municipalities requiring backwater valves to be installed in new homes<br>- City of Vancouver, BC is converting their combined sewers into two-pipe separated sewer systems to eliminate CSOs by 2050 (Vancouver, 2016).<br>- Clean Water and Wastewater Fund announced $62 million for the Ottawa combined sewage tunnel to reduce CSOs to Ottawa river.<br>- Extensive Sewer Separation in the Oxford-Atlas-Wellington (OAW) Area, the largest contributor of combined sewage flow in the City, was initiated in 2004. This was a joint effort with the Region of Niagara and the new OAW sewer is now complete with preparations to complete final connections underway. The estimated combined sewage reduction is 5-10%, increasing the estimated total wet weather flow capture rate to approximately 73% (based on the typical year of 1980 and RVA modeling results). Bypass of the WWTP will also be reduced through reduction in wet weather flows.<br>- Upgrades to pumping stations, increasing pipe capacity and expansion of the WWTP to increase capacity (AMEC, 2012). | - Programs implemented on private property (e.g., backwater valves, drain disconnection, clean-out capping) face barriers to implementation if property owners are not willing to complete<br>- Maintenance of backwater valves must be completed by property/home owners, and may not be done. When property is sold, information may not be passed on to new owners regarding maintenance.<br>- Motivations are unknown for municipalities to choose between low impact development/green infrastructure to reduce stormwater volume versus expensive grey infrastructure upgrades.<br>- Higher initial costs associated with LID/GI.<br>- Lack of a funding model dedicated to CSO upgrade/sewer separation and on-going maintenance of the system.<br>- Lack of community participation in City programs aimed at mitigation/reduction of stormwater runoff into the combined system.<br>- Fear of liability for accessing private property to investigate I/I issues | - Low impact development Guidance: CVC Low Impact Development Road Retrofits Guide, CVC Low Impact Development Business and Multi-Residential Retrofit Guide, CVC Low Impact Development Public Lands Retrofits Guide, CVC Low Impact Development Residential Retrofits Guide, CVC and TRCA Low Impact Development Design Guide, CVC Low Impact Development Construction Guide, CVC and TRCA Landscape Design Guide for Low Impact Development and CVC Low Impact Development Certification Protocols: Bio-retention Practices, International Best Management Practices Database.<br>- Incentivize conservation measures such as downspout disconnection, installation of low-flow toilets and energy efficient washing machines and rain barrels (AMEC, 2012).<br>- Flow monitoring in all new subdivisions to identify I/I issues before infrastructure assumed by municipalities<br>- Require flood protection, I/I reduction measures for all new construction (because it is difficult to get homeowners to retrofit) | - Need for dedicated funding to address CSO issues nationally.<br>- Need for standards to reduce stormwater runoff volumes contributing to CSOs. |
| | - Sanitary/combined sewers in floodplain may be vulnerable to exposure and damage due to erosion | | - Construction/reconstruction of sewers outside of erosion-prone areas<br>- Risk assessments conducted for infrastructure within floodplain<br>- Bank stabilization works to address erosion | - Some municipalities assess risk to infrastructure due to watercourse crossing | - Costs associated with reconstruction and bank stabilization is a barrier<br>- Root cause of excessive erosion needs to be addressed for a long-term adaptation solution | - Risk assessment i.e.: PIEVC to identify sewers within the floodplain and course of action. | - Funding for implementation to address highly vulnerable infrastructure located in high risk areas. |

| Climate Parameter | Impact | Interaction with Watershed Systems | Adaptation Measure or Best Management Practices for Mitigation | State of Adaptation "What is being done?" | Gaps/Barriers | Existing Tools/Practices Addressing the Gaps / Barriers | Recommendations/Opportunities to Address Remaining Gaps |
|---|---|---|---|---|---|---|---|
| WATER INFRASTRUCTURE (WASTEWATER) | | | | | | | |
| | - Wastewater treatment plants are vulnerable to sewage bypass due to sewer overflows and inflow/infiltration of wet weather flows | | - Reduce inflow/infiltration to sanitary sewer system to reduce frequency of bypass<br>- Use real-time monitoring of wastewater system (e.g., SCADA) to predict and adjust to wet weather flows at treatment plant<br>- Increase capacity at treatment plant | - Municipalities undertaking programs to reduce inflow/infiltration<br>- Many municipalities use real time monitoring of wastewater systems | - Programs implemented on private property (e.g., drain disconnection, clean-out capping) face barriers to implementation if property owners are not willing to complete | - Risk assessment i.e.: PIEVC to identify events that surpass capacity and provide a course of action. | - Funding for implementation to address sewage bypass events |
| Temperature | - Pumping stations and treatment systems (e.g., aerators) can be at risk of electrical failure during periods of extreme summer heat due to overheating of building electrical systems (Genivar, 2011). | - If an event results in discharge of partially treated sewage due to failure of treatment systems, can result in impacts to receiving water quality.<br>- Increased concentration of parameters such as unionized ammonia. | - Cooling systems with back-up power to reduce likelihood of overheating | - Emergency management programs | - No knowledge gaps or barriers identified. | - Harmonized Extreme Heat Warning: Toronto Public Health participated in a pilot Provincial Harmonized Heat Alert and Response System (HARS). Extended Heat Warnings are issued if conditions are forecasted to continue for 3 or more days. | - Opportunity to coordinate heat alert notifications with operators to be extra cautious and ensure proper cooling measures and back-up power generators are in place. |
| Drought | - Drought conditions resulting from low precipitation and high evapotranspiration can reduce flows and thereby assimilative capacity of surface water to which wastewater is being discharged.<br>- Less dilution of wastewater due to conservation efforts during drought periods can result in more concentrated influent flows which are harder to disinfect. | - Increased frequency of drought and lowering stream flows may reduce assimilative capacity downstream of treatment facility | - Additional water quality treatment to meet effluent water quality requirements under lower flow conditions<br>- Real-time monitoring of surface water receivers | - Water restrictions/water conservation measures<br>- LID/GI can be implemented upstream to increase assimilative capacity of receiving streams during drought conditions. | - No regulations for LID despite wealth of guidance documents and performance monitoring results i.e.: International Best Management Practices Database. | - Low impact development Guidance: CVC Low Impact Development Road Retrofits Guide, CVC Low Impact Development Business and Multi-Residential Retrofit Guide, CVC Low Impact Development Public Lands Retrofits Guide, CVC Low Impact Development Residential Retrofits Guide, CVC and TRCA Low Impact Development Design Guide, CVC Low Impact Development Construction Guide, CVC and TRCA Landscape Design Guide for Low Impact Development and CVC Low Impact Development Certification Protocols: Bio-retention Practices. | - Need for standards to allow for low impact development and green infrastructure implementation to address assimilative capacity issues |

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# Appendix C
# Infrastructure Adaptation Case Studies

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# Case Studies on Advancing Adaptation to Climate Change

## Toronto Hydro Electrical Distribution Infrastructure Case Study

Toronto Hydro is considering climate change in a systemic way, integrating consideration of future risk into existing policies, practices and procedures. The PIEVC Protocol served as the means by which the organization could systematically explore its climate change risks and raise staff and organizational awareness of climate change issues, both within Toronto Hydro and in the larger Canadian power utility community.

Toronto Hydro is the largest municipal electrical distribution company in Canada and serves its largest city, Toronto (pop. 2.8 million, 2015). As of June 2015, the utility supplies approximately 740,000 customers and owns approximately $3B worth of overhead, underground, and distribution assets.

Toronto Hydro completed two PIEVC studies, one in 2012 and another in 2015, exploring both the current and projected impacts of climate change respectively on their distribution assets. Following this work, an internal working group bringing together specialists from across Toronto Hydro's Engineering and Investment Planning Division was formed to examine ways of integrating the findings and learnings (e.g., vulnerabilities, risks and possible avenues for adaptation) from these studies into its system planning, standards, maintenance and procurement practices and procedures. Internal groups best suited to take on these responsibilities were also identified.

At the end of December 2015, this working group developed an internal report highlighting 14 different initiatives that could be undertaken, which were then assigned in January 2016 to the four main departments most suited to helping the organization adapt to a changing climate. The four departments were:

- Standards and Policy Planning Department (e.g., responsible for system and equipment specifications and design);
- System Planning Department (i.e., one to five year planning timeframe);
- Long Term Strategy and Planning Department (i.e., planning beyond 5 years); and,
- Generation and Capacity Planning Department (e.g., responsible for relationships with generator utilities, as well as distributed generation and station management).

Examples of the 14 initiatives include:

- The Standards and Policy Department is re-examining the technical specifications of major equipment (e.g., transformers, cables, conductors) to determine whether they align with projected climate conditions. This work could result in changes to procurement specifications for all new equipment where necessary;
- A review conducted by the System Planning Department to determine whether climate change risks are adequately reflected within system planning guidelines and criteria. These guidelines and criteria are used to determine the kinds of projects (e.g., new construction, renovation, rehabilitation) that are appropriate for specific areas, and whether better equipment or construction standards are required in locations prone to flood, wind damage, etc.;
- The Long Term Strategy and Planning Department is undertaking a review of the maintenance manual through a climate change lens to assess whether current maintenance practices, which are designed to ensure assets achieve their expected lifespan, require adjustment (e.g., increased frequency of checks, more monitoring);

- The Generation and Capacity Planning Department is conducting a station by station evaluation of vulnerabilities to identify those which are particularly vulnerable to extreme events but are not already included in any upcoming work programs.

To support these initiatives, Toronto Hydro will also continue to monitor the development and refinement of climate change information to ensure that the climate projections and trends they employ are aligned with other work occurring in the City, province and industry.

Overall, Toronto Hydro staff reported an important shift in the organization s thinking about climate change. It is now seen as a high profile issue for the organization, and internal senior management has provided substantive support to address these issues on an ongoing basis.

Toronto Hydro has been actively involved in outreach activities to enhance knowledge on the issue within the wider power sector. Since the PIEVC assessment, staff gave a presentation on the organization s initiatives at the Electricity Distribution Association EDIST 2015 conference where utilities, mostly from Ontario, as well as other areas in Canada, were in attendance. They also presented their work at the Canadian Energy Association s annual general meeting. They are involved with the City of Toronto s Resilient City Working Groups and collaborating with other groups in the City such as Transit, Water, Buildings, Social Planning, as well as external agencies such as Metrolinx, Hydro One and the TTC. As part of the Resilient City Working Group, Toronto Hydro is part of a sub-working group involving other utilities such as telecommunications which is looking at climate change risks and resilience. Currently, Toronto Hydro has no specific climate change focused outreach activities with the general public.

Toronto Hydro s ongoing work to review existing standards and planning guidelines showcases how integration of climate change into the design and construction of equipment can be integrated within current practices. In many ways, existing budgets are being used to support climate change work, and constant upgrading of their systems provides multiple opportunities to include consideration of climate change into the system renewal. It was estimated that the total human resources dedicated to climate adaptation issues would be the equivalent of one full time person. However, Toronto Hydro s approach of spreading out the workload among over a dozen key individuals ensures that the issue is taken up throughout the organization, within different departments and from multiple perspectives.

The main challenge identified by the organization to climate adaptation is the proper management of resources dedicated to the climate adaptation issues, since it is only one among the many priorities and tasks attributed to staff. Technical challenges will also arise in the future, such as space constraints for newer or upsized equipment that may need to fit into existing and confined spaces especially in downtown and inner city neighborhoods.

In summary, Toronto Hydro s approach to climate adaptation is to integrate these efforts within existing programming and work, rather than to create a separate team or work stream to address these issues. Initiatives covered a broad spectrum of potential adaptation avenues, covering planning and engineering, system design, procurement policies, internal communications and further investigation. Furthermore, Toronto Hydro is involved on an ongoing basis on outreach activities to enhance climate resilience in the power sector and for the City of Toronto. Toronto Hydro as an organization, and through its senior management, has demonstrated ongoing support and commitment to addressing climate change. Toronto Hydro found that undertaking the PIEVC Protocol was an extremely useful exercise. It served as the means through which the organization could concretely explore its climate change risks and raise staff and organizational awareness of climate change issues.

*Replicated from Natural Resources Canada (2016). Impacts of the Application of the PIEVC - Infrastructure Risk Assessment Tool, prepared by AECOM, August, 2016.*

## British Columbia Ministry of Transportation and Infrastructure Provincial Highway Infrastructure Case Study

British Columbia Ministry of Transportation and Infrastructure (BCMoTI) now requires all construction, rehabilitation and maintenance work on provincial highway infrastructure to consider the impacts of climate change and extreme weather events. The PIEVC assessment methodology has been a catalyst in helping the Ministry identify vulnerability to climate changes and thus mainstream climate change adaptation and formalize it within the engineering and design practice of the Ministry and providing a vehicle to the wider engineering community for adopting a climate adaptation mindset.

The BCMoTI is responsible for providing vital provincial transportation infrastructure, transportation services, undertaking transportation planning and policy development, and providing emergency management services. Staff at BCMoTI and consultants undertook five separate PIEVC assessments of infrastructure along sections for highway across the province between 2010 and 2015 to understand how climate change and extreme weather events may impact their assets and operations in different geographic regions of the province.

The process provided Ministry staff with important learnings about the vulnerabilities in the provincial highway system to a changing climate, and created a strong awareness of the need to integrate climate adaptation in current practices. One of the key impacts of a changing climate is more intense precipitation events leading to higher runoff and potential inadequacies in drainage components of infrastructure. While the Ministry has concluded that current infrastructure may not need to be rebuilt or retrofitted immediately, maintenance, rehabilitation and new construction need to take the potential impacts of climate change into account.

One of the key outcomes of these learnings is the publication of a Technical Circular directed at internal ministry staff and engineering design consultants who work on provincial highway projects. Technical Circulars are used to “ensure timely and uniform application of technical standards and practices within the B.C. transportation community. [They] clarify, modify or introduce new practices in the application of technical issues.”[41] The Technical Circular, *Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design*, requires:

*“All infrastructure engineering design work to evaluate and consider vulnerability associated with future climate change and extreme weather events and to include appropriate adaptation measures where feasible, to mitigate against future consequences over the design life of the infrastructure.”*

Generally, it requires a demonstration by design engineers that reasonable consideration of climate change and extreme weather events has been taken into account for all new construction, rehabilitation and maintenance projects as appropriate to the scale of the project. Assets with shorter design life or lower traffic volumes may require a smaller scale analysis, while major projects with longer design lives would require a larger scale, or more rigorous analysis. The technical circular directs practitioners towards climate projection information sources as well as existing vulnerability assessments in order to help understand potential climate change impacts. It also requires them to identify vulnerable infrastructure components and develop adaptation strategies and design criteria to be incorporated into a project.

The process outlined by the technical circular is prescriptive in the sense that a demonstration of climate change consideration and adaptation must be made, but it is not prescriptive in the design outcomes. Through undertaking the PIEVC assessment process and participating in PIEVC activities, BCMoTI staff arrived at the conclusion that the engineering design process did not need to be changed, but consideration and review of the types of data indicated in codes and standards that were crucial to the design process was necessary.

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[41] *Government of British Columbia, http://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/engineeringstandards-guidelines/technical-circulars*

In the age of digital modelling and design, it is especially important for designers and engineers to understand and question the assumptions and data that underlie the models they use, and to ensure that they are not based on outdated climate data. One of the required technical circular products demonstrating that climate change is considered are design criteria sheets which outline changes in design specifications of specific infrastructure components (e.g., culvert sizing) including climate based justification for changes. Over time it is hoped that the use and subsequent review of these sheets will allow the Ministry to track infrastructure adaptation to climate change, with respect to the decisions that went into climate resilient design.

The Technical Circular developed by the BCMoTI is as important a result as the process used to develop it. In fall 2014, BCMoTI staff sat down with a committee at large of the Association of Consulting Engineering Companies of BC (ACECBC) to discuss the need and justification for consideration of climate change. A smaller subcommittee was then convened to produce the technical circular, released 18 months later. Following the publication of the Technical Circular, the Association of Professional Engineers and Geoscientists of BC (APEGBC) began developing a practice guide for transportation engineering design adaptation to climate change, which is slated to be released in spring 2016. The process is helping the wider engineering community establish how to consider climate adaptation and promote climate resilience within the transportation engineering design practice.

BCMoTI leadership on climate adaptation has been supplemented by other outreach activities such as staff presentations of learnings and adaptation processes at national conferences. Recently, BCMoTI staff assisted the BC Ministry of Forests Lands and Natural Resource Operations (FLNRO) undertake climate change vulnerability assessments of some of its forest service roads.

This BCMoTI case study clearly demonstrates that climate adaptation is as much a structured process of vulnerability assessment and decision making, as it is about strengthened, better maintained, and more robust infrastructure. The main challenges identified by BCMoTI staff revolve around wider uptake of the process by engineers and designers, especially in the engineering consulting community.

Correspondingly, BCMoTI staff drew parallels between the process of climate change adaptation today, and the process for considering environmental impacts in highway design 15 to 20 years ago. At that time, consideration of the environmental impacts of highway construction and mitigation of impacts were only beginning to be incorporated into design processes. Today, it is inconceivable to undertake transportation design projects without an environmental impact assessment on ecology, flora, fauna, etc., and development of impact mitigation measures.

BCMoTI staff are confident that leadership, as demonstrated through release of the Technical Circular, and initiatives like the APEGBC practice guide, will go towards mainstreaming and normalizing climate change adaptation practices in transportation engineering as has occurred for environmental practices.

*Replicated from Natural Resources Canada (2016). Impacts of the Application of the PIEVC - Infrastructure Risk Assessment Tool, prepared by AECOM, August, 2016.*

# City of Castlegar
# Stormwater Infrastructure Case Study

The results of a PIEVC Protocol assessment on stormwater infrastructure provided decision makers in Castlegar, B.C., with concrete evidence of vulnerabilities and the need for climate adaptation. This small rural community was able to use these findings to justify and develop a range of low cost planning, maintenance and funding mechanisms that are designed to improve the resiliency of its stormwater management system. As a result of these efforts, City of Castlegar is recognized as a thought leader in climate adaptation for small communities.

The City of Castlegar (population approx. 8000 in 2011), is a rural community located along at the confluence of the Columbia and Kootenay Rivers in the interior of British Columbia. Its urban area is nestled in the river valley and surrounded by steep mountainous terrain on all sides. Numerous creeks collecting water across the mountainsides flow through the built environment to drain into the rivers below. Many of the creeks are channeled through culverts and pipes as they cross the community. As a result, the city's stormwater drainage system is particular vulnerable to intense rainfall events that may overwhelm drainage capacity and cause flooding.

Staff at the Department of Transportation and Civic Works of the City of Castlegar completed a PIEVC assessment of their stormwater infrastructure in 2010. Learnings from this assessment, as well as subsequent storm events that followed in 2012, have led to an increased recognition of the threats of climate change and an increased awareness of vulnerabilities by City staff and Council. This has led to the undertaking of numerous low cost initiatives to enhance resilience of this small rural community in the face of extreme weather events and climate change.

The City is developing a Stormwater Master Plan, which considers the impacts of climate change. Furthermore, city staff has completed small projects to armour certain stream channels to reduce erosion risks during high runoff events. Following the recommendations of the 2010 PIEVC assessment, staff now also conducts regular inspections and clear debris proactively along stream channels in advance of storm events to reduce the chances of blockages of stormwater pipes and intakes (e.g., clearing trash racks, logs and other debris along stream courses).

To help fund these stormwater planning and management activities, City staff recognized the need for a separate and dedicated stream of funding beyond the regular budget. At the time of writing, a flat tax of $150/parcel is being proposed to city council. The interviewee noted that the learnings of the PIEVC Protocol, during which members of council had participated, helped to raise the profile of climate adaptation, and has directly contributed to the proposal to create this dedicated funding stream.

The City of Castlegar is also partnering with three other municipalities in the region to update their Development and Servicing By-laws. These by-laws dictate infrastructure requirements for new developments and subdivisions, and cover such elements as hillside development, road width, site servicing requirements and community amenities. As part of this revision, staffs from these municipalities are incorporating guidelines on how to address climate change impacts to stormwater systems, including potential provisions requiring stormwater reuse on site and raingardens to reduce runoff. The finalization and adoption of revised by-laws is not anticipated until 2017.

Castlegar staff has given several presentations through the Columbia Basin Trust to municipalities in the region to promote greater awareness of climate change impacts to stormwater systems. Presentations have focused on their PIEVC assessment work as well as on the development of their Stormwater Management Plan. They also collaborated with the Institute of Catastrophic Loss Reduction in the publication of a book chapter on stormwater management. In parallel with these efforts, the Government of British Columbia has recently been requiring all municipalities to develop asset management plans for their infrastructure as a pre-requisite to receiving funding or grants for infrastructure work. Due to the outreach activities and progressive work that the City of Castlegar has undertaken, they were awarded in 2016 a $250,000 grant funded by the federal gas tax to help pilot a study on how to integrate climate change related risks to stormwater management into Castlegar s Asset Management Plan. These efforts will then be showcased to other municipalities facing the same challenges.

In summary, the City of Castlegar has undertaken a range of planning, funding, maintenance and outreach efforts that were born from the learnings and efforts made during their PIEVC study. These subsequent actions that will help improve the resilience of their stormwater system to a changing climate. Their outreach and engagement activities with other municipalities are showcasing their leadership as well as promoting wider awareness and resilience across the region.

*Replicated from Natural Resources Canada (2016).Impacts of the Application of the PIEVC - Infrastructure Risk Assessment Tool, prepared by AECOM, August, 2016.*

# Municipality of the District of Shelburne Wastewater Treatment Plant Case Study

The District of Shelburne undertook a PIEVC Case study at the design phase for a new wastewater treatment plant. Findings from the PIEVC Protocol were incorporated into the design and construction of the new plant, enhancing its resilience to extreme weather and climate change.

The Municipality of the District of Shelburne (MDS, population approx. 4,400 in 2011) is a rural coastal community on the southeastern tip of Nova Scotia. Staff at MDS conducted a PIEVC Protocol assessment in 2011 on a proposed design for a new sewage treatment plan (STP) that was eventually commissioned in 2012. The new STP replaced the old sewage treatment plant, which was operating over its design capacity and did not meet effluent discharge limits. Furthermore, the old STP was vulnerable to intense rainfall events, which increased flows to the plant and affected its performance. It was also vulnerable to sea level rise and storm surge impacts given its location near the shoreline. The new STP is located up the hill approximately 1 km away from the old plant, and projected sea level rise is no longer a concern.

Unlike other PIEVC Protocol case studies, this study was unique because the assessment was focused on the designs and specifications for a plant which had not yet been built. Therefore, it could not draw as heavily upon experience with past, extreme weather impacts on the infrastructure to guide the vulnerability assessment.

However, based on the preliminary design, design standards and best practices at the time, study practitioners were able to conduct a vulnerability assessment and identify areas where the intended design could be improved in the face of projected climate changes. In addition, the risk assessment workshop served as a valuable learning exercise because it brought a diverse set of specialists together to talk through potential climate change risks relating to the design and operation of the new facility.

The learnings from the PIEVC assessment were subsequently integrated into the final design and construction of the new STP. According to the interviewee, there have not been any weather related incidents at the new plant since operations commenced in 2012.

Shelburne s STP received the 2014 Union of Nova Scotia Municipalities Climate Change Leader s Award, which recognizes exemplary leadership in climate adaptation through implementation of initiatives or the creation of awareness. In this case, the award recognized the municipality for its leadership in incorporating climate change projections into the design of its new facility.

*Replicated from Natural Resources Canada (2016).Impacts of the Application of the PIEVC - Infrastructure Risk Assessment Tool, prepared by AECOM, August, 2016.*

# Elm Drive: Low Impact Development Demonstration Site Case Study

## Context

Almost every year since 1995, Ontario has had a state of emergency linked to severe weather[42]. Climate change is predicted to exacerbate the risks and challenges municipalities face today with aging infrastructure and growth pressures[43]. The serious impact of storm events, such as the one that took place on July 8, 2013 in the Greater Toronto Area, calls attention to the need to build additional stormwater capacity within our urban areas to handle these large, intense rainfall events. High intensity storms produce heavy rainfall in very short time periods. Large volumes of stormwater runoff overstress conventional stormwater systems leading to flooding, erosion, habitat destruction, degraded water quality, damage to infrastructure systems and post-flooding health-related concerns including mould growth and contaminated water.

Our approach needs to change in order to stay ahead of stormwater challenges. We need to think of stormwater management not just in terms of dealing with storms, but as managing our water cycle during dry periods to optimize integrated water management (water, wastewater and stormwater). We need to be able to manage extreme rainfall events like July 8, 2013, combination events like the excessive rain and snow runoff causing the Bow River flood in Calgary in 2013, and extended periods of drought as occurred in southern Ontario in 2007 and 2016. These types of events are increasing in frequency and have costly consequences including power outages and costly property damage.

Green infrastructure, including low impact development (LID), is gaining traction as an approach to enhance stormwater management within existing urban areas to reduce stress on aging infrastructure. LID has been found to build resiliency, optimize water and wastewater treatment costs, and improve watershed health and the local economy. LID can also contribute to cost savings; a recent report generated estimates of the

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[42]Sandink, D., Kovacs, P., Oulahen,G., & McGillivray, G. 2010. Making Flood Insurable for Canadian Homeowners: A Discussion Paper. Toronto: Institute for Catastrophic Loss Reduction & Swiss Reinsurance Company Ltd. Available at URL: http://www.iclr.org/images/Making_Flood_Insurable_for_Canada.pdf.

[43]Zimmerman, R. and Faris, C. 2010. Chapter 4: Infrastructure impacts and adaptation challenges. Annals of the New York Academy of Sciences, 1196(1), 63-86.

monetary value of flood loss avoidance that could be achieved by green infrastructure implemented watershed-wide, in new development and redevelopment, in the United States[44].

LID technologies are designed to mimic the natural movement of water in the environment. They are engineered landscape features that infiltrate, filter and store stormwater runoff. They also provide surfaces for evaporation to occur. By emulating natural or pre-development conditions at a site, LID technologies help reduce the volume of runoff, removing nutrients, pathogens and metals. LID technologies can also restore groundwater and stream flows, support wastewater dilution, protect our fisheries and enhance human well-being.

## Project Description

LID projects are easy to incorporate into new developments, urban retrofits or redevelopments. An example is CVC's right-of-way demonstration site at Elm Drive in Mississauga. The City of Mississauga the Peel District School Board and Credit Valley Conservation collaborated to develop this green-street project, located approximately two blocks south of the Square One mall. The project is located on a mixed-use street with residential homes and an education centre. Features onsite include a permeable pavement sidewalk and laybys, and a series of six Bio-retention cells connected with an underdrain. CVC monitors the quantity and quality of runoff leaving the site. The site provides stormwater treatment, improving the quality of stormwater discharged to Cooksville Creek including thermal mitigation, and reduces the runoff volume to municipal storm sewers.

Elm Drive is just one of the many projects implemented and monitored by CVC as part of the Infrastructure Performance and Risk Assessment (IPRA) program. IPRA is a multi-year stormwater monitoring program focused on gathering detailed information to evaluate stormwater facility performance in various land use types, climate conditions and development stages. The IPRA program also evaluates the effectiveness of stormwater facilities in flood control, erosion protection, nutrient removal, cold climate performance and the maintenance of pre-development water balance.

The monitoring program is based around a set of objectives that have been developed with an advisory committee consisting of municipalities, provincial and federal environmental agencies, academia, and engineering professionals. Several of these objectives have scoped the monitoring program at Elm Drive, such as evaluate how a site with multiple LID practices treats and manages stormwater runoff; evaluate the long-term maintenance needs and impact of maintenance on performance; and, assess the quality and quantity performance of LID designs in clay or low infiltration soils.

## Project Outcomes

LID offers a quick win solution to build capacity into existing stormwater management infrastructure while conventional practices are upgraded. In existing urban areas built prior to flood control requirements, there is little available land for conventional practices such as berms or stormwater management ponds, which require a large amount of available land. LID projects can get into the ground quickly and can make use of space in public areas such as schools, parks and road right-of-way. Municipalities like Mississauga are finding that LID may be able to provide opportunities to build flood control capacity and reduce stress on existing infrastructure, particularly in the Cooksville Creek subwatershed. When incorporated into multiple locations and different land use types across a watershed, LID is an effective tool for managing the impacts

[44]Atkins. 2015. Flood Loss Avoidance Benefits of Green Infrastructure for Stormwater Management. Prepared for United States Environmental Protection Agency, December 2015. Available at URL: https://www.epa.gov/sites/production/files/2016-05/documents/flood-avoidance-green-infrastructure-12-14-2015.pdf.

of stormwater such as erosion, degrading water quality and associated costs. In doing so, LID also helps to protect natural features and biodiversity.

## Project Lessons Learned

Performance monitoring at Elm Drive has provided valuable data to address many of the gaps and barriers associated with wide LID implementation. This data has shown that the site is able to achieve substantial volume reductions for events of all sizes and provide a thermal benefit to receiving watercourses. Volume reduction is achieved by retaining water (through infiltration or evapotranspiration) such that it does not contribute to outflow from the site. It is important for groundwater recharge and water balance objectives as well as water quality objectives. Monitoring has indicated that 80% of all precipitation events at Elm Drive produce no outflow. Events up to 25 mm account for 90% of storm events in this area and contribute to a large proportion of the average annual precipitation in southern Ontario. Due to their frequency, events in this size range are also responsible for transporting a large proportion of the annual contaminant load delivered to receiving waters. For events less than 25 mm, a volume reduction of 93% was achieved, significantly reducing the amount of stormwater runoff entering Cooksville Creek.

In addition to providing volume reduction for frequent events, Elm Drive was able to manage runoff from the large 105 mm event on July 8, 2013. Elm Drive was designed to reduce the peak flows from a 100-year storm by 13%; but monitoring results from this large event found that the LID features were able to reduce the peak flow by approximately 60%, dramatically outperforming design criteria. These features also reduced runoff volume by approximately 30% (which translates to almost a 1/3 of the rainfall being diverted from the municipal system). In addition, a lag time of 20 minutes delayed flow to the storm sewers reducing stress on the already burdened municipal system.

The treatment train at Elm Drive has also proved very effective in reducing the thermal load to downstream watercourses. Data from monitoring the inflow and outflow water temperatures on site suggest that the LID features significantly improve the thermal loading impacts across all event sizes. The decrease in outflow volume through runoff storage within the LID facility is the leading factor in producing high thermal and temperature reductions at Elm Drive. Additionally, any outflow produced must pass through cooler, permeable soil where thermal energy is transferred. The treatment train provides high thermal reduction in all events ranges and nearly 100% reduction during smaller, more frequent events. The LID provides consistent event mean temperature (EMT) reductions each year, demonstrating the need to implement LID designs upstream of known sensitive streams habitats. These results suggest similar LID technologies can be used to meet Ministry of Natural Resources and Forestry requirements for protecting Redside Dace habitats.

More information on the performance of the LID features at Elm Drive and other projects can be found on our website at www.creditvalleyca.ca/low-impact-development/.

## Next Steps

In 2017 and beyond, CVC is working to continue to share and communicate key outcomes of the LID performance Monitoring program including training and webinar development. We are continuing to monitoring specific sites for longer terms to quantify maintenance requirements, costs and benefits. We are also reviewing the key monitoring objectives to refine the program objectives to include new investigations including seasonal water balance, effects on adjacent infrastructure and defining evapotranspiration contributions to LID site scale water balance.

## Fraser Health's Climate Resilience and Adaptation Program

In early 2016, BC GreenCare began exploring climate risks and impacts to the health care systems' buildings and assets, with a view to curbing disruptions to health care service delivery now and in the future. As the sustainability portfolio for BC's lower mainland health organizations, comprising e.g. an energy conservation and efficiency (i.e. mitigation) program and a staff engagement program (e.g. adaptation) among others, GreenCare's existing platforms and networks provided a framework and mechanism for a new Climate Resilience and Adaptation Program to emerge.

The nascent program's first initiatives included conducting climate risk and resilience assessments on five hospitals exposed to a range of hazards, including climatic and seismic. Many recommended measures were integrated into the lower mainland facilities management department's knowledge and risk management frameworks with a view to systematically addressing risks identified at the hospital-level. Other measures indicated the need for more in-depth study and technical analysis. To address this need, the program is now working with Fraser Canyon Hospital in Hope, BC to develop a case study showcasing the need to identify, plan and track progress in addressing climate risks and impacts at the site level and in a holistic manner. Partnerships with Health Canada's Climate Change & Innovation Bureau and with the National Research Council are key to highlighting how health care's many departments might collaborate to move forward the resilience and adaptation agenda at both the site and organization levels. As this work and its lessons are designed to be scalable and instructive, they likely will be instrumental in informing development of the 10 year organization-level plans mandated under the new BC Climate Leadership Plan.

The Green Health Care Coalition is also leading an initiative to help build resilience to climate change in Canada. The Coalition, in partnership with Health Canada, developed a Healthcare Facility Resiliency Check-list. The following peer-reviewed article describes the tool: http://www.mdpi.com/1660-4601/11/12/13097/htm

The Green Health Care Coalition's web site provides additional details: http://greenhealthcare.ca/climate-change/resiliency/.

# Linking Climate with Water Infrastructure and Social Vulnerabilities

## Credit Valley Conservation

### Context

Climate change is expected to result in more frequent impacts to water resources, including low water level conditions, as well as flooding and sewage treatment bypasses resulting from extreme rainfall events. According to Statistics Canada, of the 281 significant disasters that have occurred in Canada from 2000 to 2014, 30% have been floods, and 12% of all Canadians have experienced a major flooding emergency. At the same time, in 2007 a Federation of Canadian Municipalities and McGill University survey found that the estimated water infrastructure deficit in Canada was estimated in 2007 at $88 billion for new and existing water infrastructure, although this figure does not include the infrastructure required in urban areas currently not serviced (e.g., areas built prior to 1980s which were typically built without flood control). This suggests that current water infrastructure is not sufficient to meet current and future water resources challenges. In light of these risks, the Province of Ontario and British Columbia recognize the need to integrate water management activities, including drinking water, wastewater, stormwater, and watershed management, into one planning process, that allows municipalities to optimize infrastructure investment and reduce overall risk.

Future climate conditions are anticipated to have wide-ranging impacts on water resources; hence a risk assessment with respect to climate change is an opportunity to quantify potential future impacts on natural and municipal water systems, as well as the watershed ecosystems and communities that rely on them. Using the watershed as a study boundary reflects the physical interactions between water systems, and allows for integrated decision-making. Communities can also be negatively impacted by water system vulnerabilities, such as those resulting in flooding, causing property damage and health concerns for residents.

The relationships between water infrastructure and the community is highlighted by recent events that have occurred in the Credit River watershed, which precipitated the initiation of this study. The Credit River watershed is located within the Greater Toronto Area (GTA). In the GTA, the lower-tier municipality is responsible for stormwater, located within an upper-tier municipality, responsible for water and wastewater. By taking a watershed approach, integration between lower and upper tier municipalities can optimize infrastructure investment and ensure that adaptation measures done by one tier do not adversely impact another (e.g., sealing sanitary manholes to reduce sanitary back-up will not create overland flow concerns for the lower tier municipality). Credit River watershed is highly urbanized, and was mostly developed before 1970s prior to flood and water quality controls for stormwater. Two extreme rainfall events (August 4, 2009 and July 8, 2013) in the watershed resulted in riverine and urban flooding causing extensive damages and impacts on the community, including power outages, basement sewer backup to over 5,000 properties, flooding of streets and railways, and significant damage to property.

**Project Description**

A climate change risk assessment of integrated water management infrastructure within the Credit River watershed was commenced in 2015. This assessment was intended not only quantify existing and future risks within the watershed, but also to highlight the challenges and opportunities of conducting an integrated, watershed-based assessment of risk and vulnerability regarding stormwater, wastewater, drinking water, and watershed systems. This study also addressed the interconnections between water infrastructure vulnerability and social vulnerability within communities.

A watershed planning framework was applied to assess risk through the lens of integrated water management. Other tools, including the PIEVC Engineering Protocol and hydrologic and water quality modelling tools, were also employed. The risk assessment used three defined time horizons: baseline climate; 2050s; and 2080s.

These periods were selected as they represent key planning and operational timelines for the infrastructure systems that were considered in the assessment.

The project considered how adaptation measures can be implemented to reduce climate risks under existing and future conditions, and provides a case for investment in adaptation.

**Project Outcomes**

The outcomes of this study acknowledge that there is a pattern of risk associated with extreme rainfall events, with significant impacts on water infrastructure systems within the watershed, that extend to impacts on the community and other municipal systems, including transportation and emergency services. As a highly urbanized watershed that largely developed prior to flood control, a lack of stormwater management infrastructure in the watershed has led to vulnerability to flooding events. The impacts of flooding were not confined to water infrastructure, as they extended into impacts on emergency response during flooding events, and health impacts. Through this project, an understanding was gained regarding the impacts on sensitive populations and areas, including seniors, medical centres, and low-income neighbourhoods during flood events.

**Impacts to the Community**

This study examined previous events of flooding to assess current and future risk. The impacts to the community and members of the public stemming from water infrastructure vulnerability. During the event, flooding of homes occurred within and outside of the floodplain through various mechanisms including sanitary sewer backup and overland flooding. In addition to property damage, some residents were forced to relocate due to damage to homes, including basement apartments, and in some cases could not return for months due to mold growth.

The overall risk associated with extreme rainfall events was deemed higher due to impacts and potential impacts on residents during the event itself. For example, during historical extreme rainfall events in the Credit River watershed, some residents could not receive needed in-home medical care during the event due to roads being impassable due to stormwater flowing over roadways. This resulted in additional calls to 911 for emergency care, increasing strain on emergency services during the event. A near-miss during the July 8, 2013 event was the flooding of a school in the Credit River floodplain, where up to four feet of water flooded the kindergarten classroom in less than two hours. Had this event occurred only two weeks earlier before summer vacation, the impact of this event may have been much higher than was observed.

Another near-miss during the July 8, 2013 was the discovery that a portion of train-track along the Go Transit Lakeshore line had been undermined and washed out by riverine spill. Operators were fortunately alerted to this fact by a person who noticed the washout, and the train did not cross the undermined track.

### Vulnerability Mapping

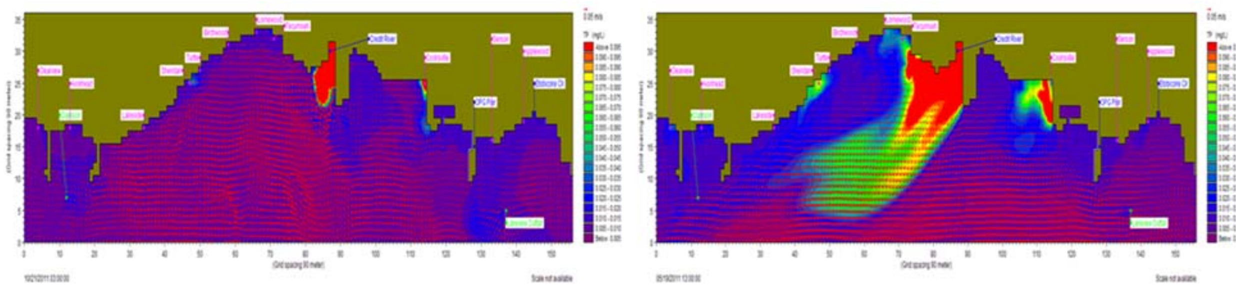
One of the key findings of this study was the wide range of impacts of flooding. The impacts of extreme rainfall on vulnerable populations, including the elderly, children, and basement apartment-dwellers was noted through examples from historical flooding events. Mapping was created to overlay areas prone to flooding with these populations, as well as critical infrastructure such as schools, medical centres, evacuation centres, and emergency response services locations. A model was created using GIS software to develop a vulnerability ranking system within the Credit River watershed in terms of vulnerable populations and infrastructure, to be used for prioritizing water management and emergency response during flood events. While traditional approaches to water management consider drinking water, wastewater, and stormwater management decisions in isolation, this assessment highlights the benefit of integrating social considerations into infrastructure decision-making, which can impact decisions-making. The mapping created for this assessment indicated that areas for prioritization are different based on what factors are being considered, and highlight the need to consider all potential impacts of extreme rainfall and flooding events when investing in adaptation measures.

### Impacts on Lake Water Quality

The study also considered the connections between climate, stormwater management level of service, and water quality in streams and the nearshore of Lake Ontario. Extreme events bring high loads of contaminants to receiving streams and lakes, and affect the nearshore water quality. The contaminant loads depends on sediment transportation as well as density of water, which dictates how far or how deep the contaminants will disperse into the lake. CVC's real-time water quality network demonstrated the high the sediment concentration during the July 8, 2013 storm event, compared to sediment concentrations during ambient weather conditions.

**Sediment transported through a GTA Creek (left) and into Lake Ontario (right) are visible following the July 8, 2013 event**

The real time water quality network was also able to capture some of very high chloride concentration events in the stream that were used to estimating density of the water and ultimately delivery of the contaminants to the lake. These observations are important for risk assessment and management decisions knowing that drinking water intakes are located in the nearshore area and are influenced by these factors. Further investigation will be conducted on the relationships between riverine and nearshore systems through real time monitoring to further understand the connections between stormwater, the watershed, and impacts to ecosystems, recreation, and water infrastructure within the nearshore.



**The movement of a nutrient plume into Lake Ontario at normal water density (left) surfs and disperses on the lake water, while at elevated density (right) the plume dives down into the lake water.**

### Understanding Algae Growth

In the study area, there have been historic examples of early emergence of algae in stream and nearshore lake areas. This resulted in damage to one of the drinking water treatment plants whose intake is located in the nearshore area of the lake. It was found that winter (December, January, February) temperatures leading up to the algae bloom were significantly warmer than other years and the 30 year normal. Additionally, because of the warmer temperatures, the majority of the precipitation over the winter fell in the form of rain, rather than snow.

The factors contributing to growth of cladophora algae include climate factors and water quality parameters, which can be influenced by stormwater management level of service, particularly with respect to water quality control. As part of this study, in-stream water quality targets were set based on the conditions and uses of the stream and nearshore. Water quality modelling of stormwater management scenarios was conducted to understand how these targets could be met considering future climate conditions.

### Project Lessons Learned

The lessons learned from the Credit River watershed apply to both the risk assessment process, as well as to integrated water management in general. Some of the lessons learned include the following.

- The watershed is the boundary over which integrated water management risk assessment should be conducted, as this area clearly defines the interconnections between water systems which are physically connected within a watershed boundary;
- Traditional water management approaches have prioritized upgrades based on age and condition of an asset; but this assessment indicates that this approach may neglect the importance of level of service of existing infrastructure, and the potential risk that failure of a water infrastructure asset may have on other infrastructure or the community and economy;
- Risk assessment of water systems should incorporate socio-economic implications of climatic events on the community and environment;
- Coordination across regional and local agencies is important with respect to defining roles and responsibilities for water management, and ensuring that adaptation measures meet the needs of the entire watershed and community, rather than being specific to one water infrastructure system;
- Adaptation to climate risk to water infrastructure is not limited to investment in water infrastructure, and can also include land acquisition, compatible land use planning, and emergency management and preparedness;
- It is useful to set instream targets for water quality that can be used to determine an appropriate level of service for stormwater management;

- Forensic investigation following an extreme climatic event is useful in determining impacts and comparing adaptation measures.

**Next Steps**

Phase 1 of the Credit River Vulnerability Assessment was completed in 2016, and Phase 2 is in progress. The objective of Phase 2 is to compare different adaptation measures specific to extreme rainfall and flooding, and to quantify the impact of each on reducing overall risk to infrastructure, ecosystems, property, and the community. The outcomes from Phase 2 of the Credit River Vulnerability Assessment will be used to develop a Risk and Return-on-Investment Tool to assist other communities in quantifying and adapting to climate risks such as flooding. The lessons learned from this study will also inform development of quality management standards for wastewater and stormwater provide municipal staff with a tool to assess risk, identify roles and responsibilities, engage, educate and gain commitment for investment in water management.

# Appendix D Infrastructure Adaptation Resources

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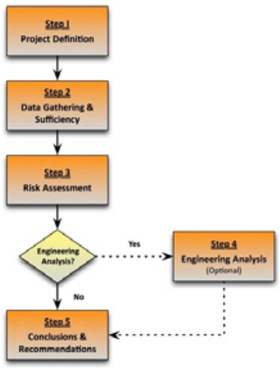
## Table D-1 Resources for Literature Review to Date: Type of Resources, Infrastructure covered

| Name of Adaptation Tool, Practice, Guideline | Tool | Practice | Study | Guideline | Infrastructure[1] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | SW | DW | WW | Watershed |
| Tools for watershed CC Vulnerability Assessment for Watersheds | X | | | X | | | | X |
| ESSA Technologies, Water Smith Research Inc, 2013, Canadian Council of the Environment | | | | | X | | X | X |
| DRAFT National Principles, Best Practices and Guidelines - Flood Mapping, AECOM for Natural Resources Canada | | | | X | X | | | X |
| NRCan Impacts of the application of PIEVC infrastructure risk assessment tool | X | | | | X | X | X | X |
| Mainstreaming Climate Change Adaptation in Canadian Water Resource Management | | | X | | X | X | X | X |
| At the Front Lines of the Flood | | | X | | X | | X | X |
| Infrastructural Adaptation: Barriers and Challenges Municipalities Encounter when responding to Climate Change | | | X | | X | | | X |
| Paying for Urban Infrastructure Adaptation in Canada | X | | X | | X | | | |
| The Adaptive Design & Assessment Policy Tool (ADAPTool) for Creating New Policies (Overview and Synthesis) | X | | | | | X | X | X |
| Canada’s Sixth National Report on Climate Change | X | | | X | X | X | X | |
| Climate Change Adaptation and Canadian Infrastructure –A review of the literature | X | X | X | X | | X | X | |
| Canada in a Changing Climate - Sector Perspectives on Impact and Adaptation | | X | | | X | X | X | |
| Climate Resilience Evaluation and Awareness Tool | X | | | | X | X | X | |
| Adapting Urban Water Systems to Climate Change (ICLEI) | | | | X | X | X | X | |
| State and Performance of Canada's Core Public Infrastructure Project | | | | X | | X | X | |
| Survey of Canadian Federal, Provincial, Territorial Climate Change Legal Provisions | | | | X | X | X | X | |
| Climate Change Planning - Canadian Communities Case studies | | | | X | X | X | X | |
| Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation (ICLEI) | | | | X | | | | |
| Climate Change Adaptation: A Priorities Plan for Canada | | | | X | | X | | X |

NOTES: Under Infrastructure Columns,
1. SW = Stormwater
DW = Drinking Water
WW = Wastewater

## Engineering



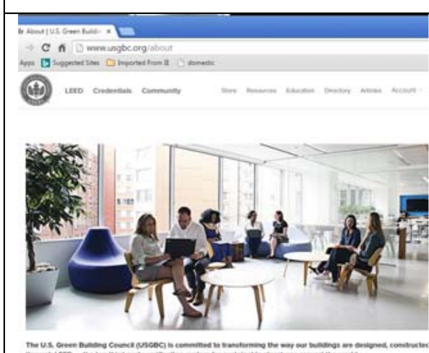

### PIEVC Engineering Protocol

The Protocol 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.

https://pievc.ca/documents


### Developing Standards (Standards Council Canada, SCC)

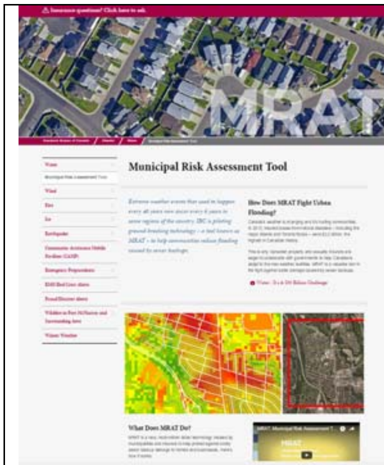
Standards development process that can be used to develop required/needed standards as identified by affected stakeholders including industry, governments, academia and public. The standards are developed through consensus by committees and can be national or international as long as all stakeholders are at the table.




### Resilient Design LEED Pilot Credits

U.S. Green Building Council offering seminars to review three new pilot credit programs to ensure that design teams incorporate planning and design for natural hazards and vulnerabilities including functionality of buildings in the event of interruptions in power or heating fuels.

http://www.usgbc.org/education/sessions/resilient-design-leed-pilot-credits-9952154




## Municipal Risk Assessment Tool

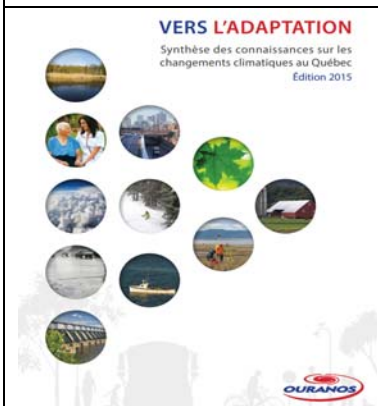
MRAT is a new, multi-million dollar technology created by municipalities and insurers to help protect against costly sewer backup damage to homes and businesses. The tool combines information about municipal infrastructure, current and future climate, and insurance claims.

http://www.ibc.ca/nb/disaster/water/municipal-risk-assessment-tool


## Building Adaptive & Resilient Communities (BARC) Program

The BARC program offers a comprehensive way to respond to the impacts of climate change, develop and implement an adaptation plan, and protect the people, property, and prosperity of your community.

http://www.icleicanada.org/programs/adaptation/barc

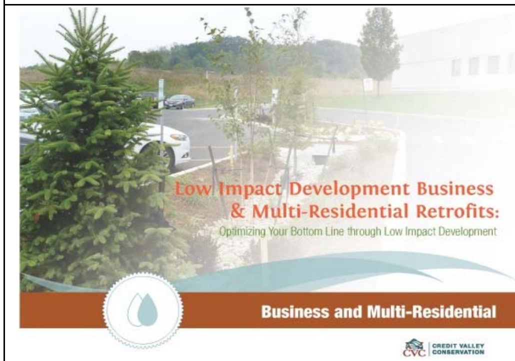



## Consortium on Regional Climatology and Adaptation to Climate Change (*Ouranos*)

The consortium provides a hub that acquires and develops knowledge on climate change and its impacts, as well as relevant socio-economic and environmental vulnerabilities, to help policy-makers identify, evaluate, promote and implement national, regional and local adaptation strategies.

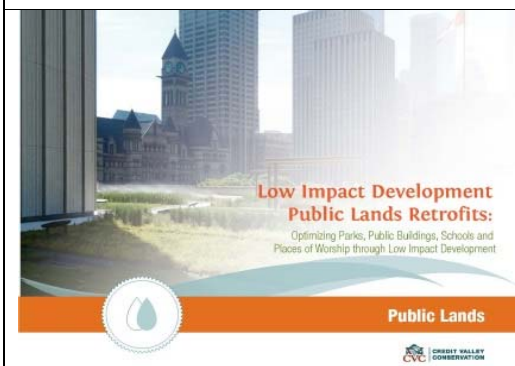
https://www.ouranos.ca/en/

## Low Impact Development




### Low Impact Development Business & Multi-Residential Retrofits

This guide provides a more cost-effective, eco-friendly stormwater management strategy for businesses, colleges, universities and multi-residential properties. It helps business determine which LID options are best suited their site and help them save money while minimizing flood and pollutant risks.

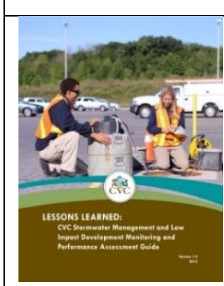



### Low Impact Development Public Lands Retrofits

This guide shows municipalities how to build stormwater management capacity in community spaces like parks, schools, municipal buildings and places of worship. It identifies quick-win projects that can be built with limited resources and large-scale projects that can be included in long-term plans.


### Low Impact Development Residential Retrofits

This guide shows how LID retrofits can improve stormwater management in older neighborhoods, saving money while helping conserve water and reduce basement flooding risks. It also shows readers how to identify neighborhoods to target for LID retrofits and collect market research data in order to develop an effective marketing plan.




### Monitoring Guide

This guide provides insight into CVC's best Low Impact Development (LID) monitoring practices. Monitoring LID practices is a powerful way to demonstrate stormwater facility performance, indicate when maintenance is needed, and inform asset management plans and infrastructure sizing decisions.


## CVC Stormwater Monitoring Strategy

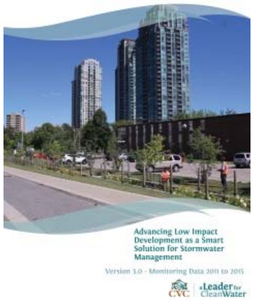
This report is intended to highlight the importance of Stormwater Monitoring in the design, construction, assumption, operation and maintenance of stormwater infrastructure to ensure long-term performance. It also provides an overview of how CVC's stormwater monitoring program fits within the priorities of watershed stakeholders.


## Credit River Water Management Strategy Update – Municipal Stormwater Financing

As program funding is identified as a barrier to the implementation of recommended stormwater management projects and was included as a key recommendation in the Credit River Water Management Strategy Update (CRWMSU) final report (CVC, April 2007), in June 2007, CVC contracted with Totten Sims Hubicki Associates (TSH) to provide an overview of various funding mechanisms employed in North America to support stormwater management (SWM) programs and conduct two conceptual financial analyses within the Credit River watershed.

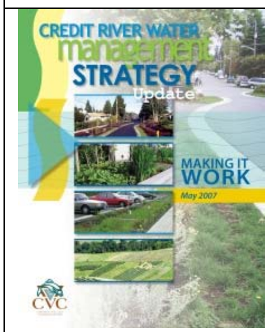

## Market Research and Marketing Strategy: Lot-level Stormwater Control in the Residential Sector

In-field market research involving owner-occupants of single-family residential dwellings was undertaken to identify opportunities and constraints for lot-level BMPs specific to Mississauga residents. The overall goal of the research was to provide a City-specific profile of the single-family residential market, enabling the development of a "Made in Mississauga" marketing strategy for lot-level stormwater control in residential areas and for municipal properties and right-of-ways



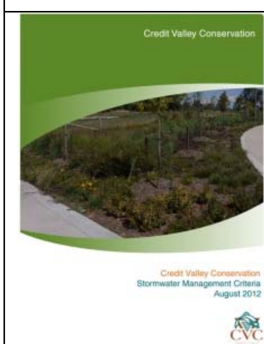

## Advancing Low Impact Development as a Smart Solution for Stormwater

The report highlights the impacts of recent extreme storm and flooding events and explains how CVC is working with partners to deliver innovative stormwater management solutions. The report is designed to allow partners and stakeholders to evaluate the success of our programs and help advance stormwater management in the watershed.




## Credit River Water Management Strategy Update

In 2008, Credit Valley Conservation decided to update its 1992 *Credit River Water Management Strategy*. The original document outlined CVC's strategy to ensure "abundant, safe, and clean water" for people and wildlife in the Credit River Watershed. The update addressed the changes to the watershed, the effects of climate change, and highlighted some of the work that had already been done in the watershed.

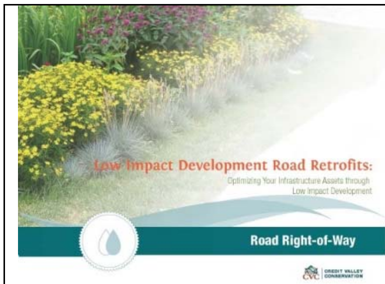



## Credit Valley Conservation Stormwater Management Criteria

This criteria document provides guidance in the planning and design of stormwater management infrastructure for developers, consultants, municipalities, and landowners, and outlines the processes and infrastructure needed to address flooding, water quality, erosion and water balance.


## Low Impact Development Design Guide

This document provides detailed design guidance on LID practices, such as components of LID systems, sizing considerations, and overcoming common design/performance concerns. It outlines how to integrate LID stormwater into the planning and review processes.



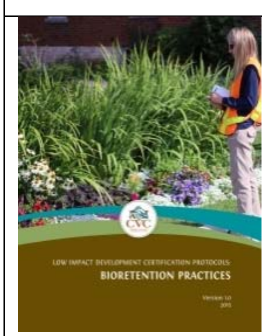

## Low Impact Development Road Retrofits

This guide helps municipalities use LID retrofits to manage stormwater on municipal road right of ways. It provides a method for determining which LID options are best suited to the road right of way project based on road type and scale. It also provides guidance on how to finance retrofits using innovative financial tools such as Gas Tax funding.

This guide shows consultants and contractors how to properly design and construct effective low impact development practices. It contains lessons learned from case studies of past construction projects and gives advice on how to avoid common design and construction mistakes.

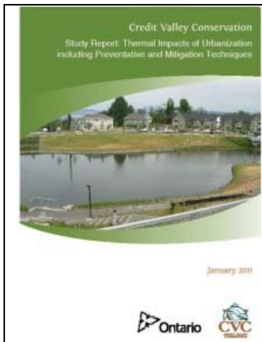

## Landscape Design Guide for Low Impact Development

This guide focuses on plant selection and feature design which are essential for both the function, public perception, and acceptance of these features in urban spaces.




## Low Impact Development Certification Protocols: Bio-retention Practices

This guide helps municipalities and property owners implement innovative LID practices by giving them a thorough understanding of certification protocols for accepting a practice from a developer. These measures help ensure an efficient and cost-effective practice that should be able to avoid the need for long term repairs.




## Study Report: Thermal Impacts of Urbanization Including Preventatives Mitigation Techniques

This report identifies urban sources of thermal loads and outlines preventative measure including LID practices, pond inlet/outlet cooling trenches and floating islands. Strong consideration is given to designing effective thermal mitigation measure in light of climate change.

## Flood Management for Municipalities and Homeowners


### Home Adaptation Assessment Program (HAAP)

As a result of a multitude of factors such as increased frequency and severity of extreme rainfall events, aging municipal infrastructure and inadequate flood protection measures at a household level, basement flood damage costs are significant across Canada. The HAAP program is a basement-flood-risk-reduction program that integrates international best practices for household flood prevention with input from homeowners and municipal engineers.

http://www.intactcentreclimateadaptation.ca/home_adaptation_assessment_program/


### Flood Smart Canada

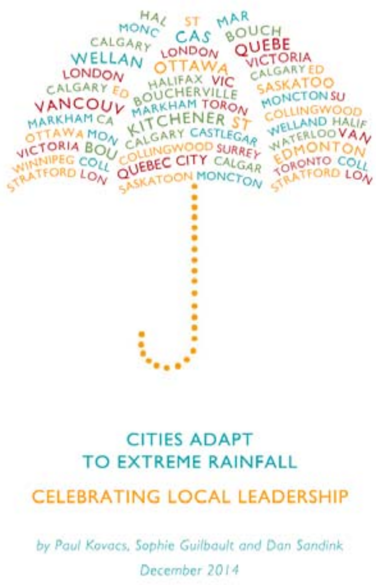
The goal is to provide a hub of information related to floods, flood risks, and emergency preparedness. The information provided is to inform the community members, organizations, businesses and municipalities about floods and to share new and existing information.

http://floodsmartcanada.ca/


### Living Shoreline Planning and Implementation

Provides the list of steps involved in planning and implementation for living in shoreline areas and the factors that need to be considered for restoration.

http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html




## Cities Adapt to Extreme Rainfall: Celebrating Local Leadership

Lead by the Institute for Catastrophic Loss Reduction (ICLR), this book provides 20 case studies of local leadership working to reduce the risk of loss and damage from extreme rainfall. The case studies reflect the idea that most loss and damage from extreme rainfall is preventable through local actions to manage waste and stormwater infrastructure combined with homeowner participation to protect their property. The case studies provide lessons learned from all the local leaders to provide insight for municipalities undergoing similar conditions looking to implement similar strategies.

http://www.iclr.org/images/CITIES_ADAPT_DIGITAL_VERSION.compressed.pdf

# Appendix E
# Glossary

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# GLOSSARY

**Adaptation**

The process of adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities (IPCC, 2014), (UNISDR, 2007), (Prasad et. al, 2009). Various types of adaptation exist; e.g., anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature shock resistant plants for sensitive ones, etc.

**Adaptive Capacity**

The ability to adjust to shocks and stresses, moderate potential damage, take advantage of opportunities, and cope or respond to consequences (IPCC, 2014). Adaptive capacity relates to the combination of strengths, attributes, and resources available within built, natural, and social systems, as well as institutions, humans, and other organisms.

**Capacity-Building**

The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions (UNISDR, 2007).

**Climate Change**

A change in the state of the climate that can be identified by changes in the mean and/or variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2014).

**Climate Change Impact**

The effects of climate change or hazardous events on built, natural, and human systems. Potential impacts are all impacts that may occur given a projected change without considering adaptation. Residual impacts are those impacts that would occur after adaptation (ICLEI, 2012).

**Exposure**

The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social or cultural assets in places that could be adversely affected (IPCC, 2014).

**Extreme Weather Event**

Extreme weather includes unexpected, unusual, unpredictable severe or unseasonal weather; weather at the extremes of the historical distribution—the range that has been seen in the past.

**Green Infrastructure**

Green infrastructure is a term that can encompass a wide array of specific practices, and a number of definitions exist. The US Environmental Protection Agency[45] defines Green infrastructure as "a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits". The American Rivers Association[46] expands on this definition; "Green infrastructure is an approach to water management that protects, restores, or mimics the natural water cycle. Green infrastructure is effective, economical, and enhances community safety and quality of life. Green infrastructure incorporates both the natural environment and engineered systems to provide clean water, conserve ecosystem values and functions, and provide a wide array of benefits to people and wildlife."

**Hazard**

Hazard refers to a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. A natural hazard is a natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2007).

**Hydrograph**

A description of water flow versus time or a description of water surface elevation in relation to a datum (stage) versus time.

**Infrastructure**

The roads, bridges, buildings, dykes, utilities, or other installations and services essential for the development, operation, and growth of a community, province/territory, or country[47].

**Integrated**

Alignment and communication between systems, sectors, and institutional processes that promotes consistency in decision making and facilitates more rapid responses by enabling systems to function collectively and achieve common outcomes (ICLEI, 2012).

**Intensity-Duration- Frequency (IDF) Relationship**

An Intensity-Duration-Frequency curve (IDF Curve) is a graphical representation of the probability that a given rainfall intensity will occur. The parameters comprising an IDF relationship are the Intensity of rainfall (mm/hr), how long it rained at that intensity or the Duration of the rainfall event and how often that rain storm repeats itself or the Frequency of the rainfall event. An IDF curve is created with long-term rainfall records collected at a rainfall monitoring station.

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[45] https://www.epa.gov/green-infrastructure/what-green-infrastructure
[46] https://www.americanrivers.org/threats-solutions/clean-water/green-infrastructure/what-is-green-infrastructure/
[47] https://atlanticadaptation.ca/en/content/glossary

**Interdependencies**

During climate change impacts, if multiple types of infrastructure are affected because of a cascading number of events.

**Local Government**

An administrative body or system in which political direction and control is exercised over the community of a city, town or small district (EEA, 2016).

**Low Impact Development**

A stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies which are intended to minimize runoff using distributed, small scale structural practices designed to mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows (CVC & TRCA, 2010).

**Mitigation**

Technological change and substitution that reduces resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks (ICLEI, 2012).

**Municipal Wastewater Treatment**
(Source: Sierra Legal Defence Fund, 2004)

**Primary Treatment** is defined as a physical process through which sewage flow is slowed down and the solids are separated from the liquids through settling. Settling most often occurs in settling tanks or sewage lagoons, during which time the heavier particles and solids in wastewater settle to the bottom and are disposed of in a variety of ways.

**Secondary Treatment** reduces the amount of suspended solids and biological oxygen demand (BOD) by breaking down the organic material present in the sewage. This is done by adding oxygen through aeration or using biological filters and layers of stones, gravel and sand. The additional oxygen activates the microorganisms present in the sewage, which break down organic matter. Enhanced secondary treatment refers to secondary treatment with phosphorus and./or nitrogen removal systems.

**Tertiary Treatment** further reduces suspended solids, BOD and other harmful substances as nitrogen, ammonia, phosphorus, heavy metals and toxic pollutants. Technologies used for tertiary treatment depend on specific characteristics of sewage. For example, additional clarifiers such as micro strainers or sand filters can further remove suspended solids and reduce BOD. Some advanced forms of filtration can remove metals and other types of contaminants.

### Peak Flow

The point of the hydrograph that has the highest flow or stage value. The maximum rate of discharge during the period of runoff during a storm event (Sen, 2016).

### Recovery

The restoration and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors (UNISDR, 2007).

### Resilience

The capacity of a social or ecological system and its component parts to cope with hazardous shocks and stresses in a timely and efficient manner by responding, adapting, and transforming in ways that restore, maintain, and even improve its essential functions, structures, while retaining the capacity for growth and change (UNISDR, 2007), (Silva, 2013).

### Resilient City

A city that is prepared to absorb and recover from any shock or stress while maintaining its essential functions, structures, and identity as well as adapting over a period of continual change. Building resilience requires identifying and assessing hazard risks, reducing vulnerability and exposure, and increasing resistance, adaptive capacity, and emergency preparedness (Mitroliou & Kavanaugh, 2015).

### Return Period

Also termed the “recurrence interval”, is an estimate of the statistical likelihood of an event to occur. It is a statistical measurement typically based on historic data denoting the average recurrent interval over an extended period of time. Return periods are usually used for risk analysis or to design structures to withstand certain return period events (e.g. 5 year, 10 year, 100 year events (Mays, 2005).

### Risk

The product of hazard and vulnerability; the likelihood or probability of occurrence of hazardous events, or trends multiplied by the harmful consequences resulting from exposure to the hazard (ICLEI, 2012).

### Risk Assessment

A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend (UNISDR, 2007).

### Risk Management

The systematic approach and practice of managing uncertainty to minimize potential harm and loss (ICLEI, 2012).

### Riverine Flooding

Caused by extreme events or a combination of extreme events such as excessive rainfall, hurricanes, snowmelt events, mixed precipitation events or ice jams. Such extreme events cause the river water levels to rise and overtop and spill into the floodplain zone.

### Runoff Volume

Stormwater runoff is rainfall that flows over the ground surface. Where rain falls on impervious surfaces, a much greater amount of runoff is generated compared to runoff from the same storm falling over a pervious area. Runoff Volume is the representation of the quantity of runoff (Beven, 2004).

### Short Duration High Intensity Rainfall

Rainfall event that occurs at a high intensity over a short period of time. For example, the GTA storm of July 8$^{th}$, 2013, had a total maximum rainfall depth of 126 mm over a 3 hour period.

### Social Infrastructure

Infrastructure and amenities that serve a social service to communities for example recreational parks, etc.

### Standardization / standards

Standardization is the development and application of standards publications that establish accepted practices, technical requirements, and terminologies for products, services, and systems. Standards help to ensure better, safer, more resilient methods and products, and are an essential element of technology, innovation, and trade. (WGACR, 2016).

### Storm Surge

The temporary increase, at a particular location, in sea level due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation at that time and place (ICLEI, 2012).

### Urban Flooding

Urban flooding results from excessive rainfall events that overwhelm the storm system (major and minor) causing inundation of properties, roads and other types of infrastructure systems. There are two types of *urban flooding*: overland flooding and basement flooding (see figures below). *Overland flooding* of buildings occurs when stormwater enters through cracks/window wells, often due to ponding from poor lot grading. *Basement flooding* occurs due to or due to a combination of overland flooding, infiltration flooding and sewer backup. Infiltration flooding plays a key role in basement flooding where soils around the property become saturated due to steady rain, spring snowmelt or extreme rainfall event.

### Urban Heat Island

The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, the changes in surface albedo, changes in pollution and aerosols (ICLEI, 2012).

### Vulnerability

The definition of vulnerability from the Intergovernmental Panel on Climate Change (IPCC) in 2014, states vulnerability as "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt".

### Vulnerability Assessment

Science-based effort to identify how and why focal resources (habitats, species, and ecosystem services) are likely to be affected by climate change (Hutto et al., 2015).

### Vulnerable Population

Vulnerable populations are defined as groups of people who are typically excluded, disadvantaged or marginalized based on their economic, environmental, social, or cultural characteristics (USAID, 2016). These population groups are most vulnerable to effects of climate change including flooding, extreme heat and air pollution. They include seniors and those in institutions, such as residential care homes; Infants and young children and asthmatics; people with chronic diseases, particularly cardiovascular and respiratory illnesses, renal disease, diabetes and obesity, as well as those taking certain medications; and people of lower socio-economic status and those living in densely populated urban neighbourhoods (Health Canada, 2008).