WEATHERING THE STORM:

DEVELOPING A CANADIAN STANDARD FOR FLOOD-RESILIENT EXISTING COMMUNITIES

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The Intact Centre on Climate Adaptation (Intact Centre) is an applied research centre at the University of Waterloo. The Intact Centre was founded in 2015 with a gift from Intact Financial Corporation, Canada's largest property and casualty insurer. The Intact Centre helps homeowners, communities and businesses to reduce risks associated with climate change and extreme weather events.

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EXECUTIVE SUMMARY

In recent years, the financial and social costs of natural catastrophes in Canada have escalated beyond historical levels. Residential flooding has been a key driver behind this trend, which has led to upward pressure on residential insurance premiums, mental health stress for homeowners impacted by flooding, potential increases in residential mortgage defaults, and lawsuits directed to builders and municipalities that fail in their fiduciary duty to anticipate and mitigate flood risk.

Fortunately, a range of practical solutions can be deployed to reduce and limit risk of flooding across a variety of circumstances. These include proactive maintenance of flood control structures, re-grading of lots and roadways, constructing new or upgrading stormwater storage facilities, and many other measures (Table 1). Public engagement and education programs on flood prevention and maintenance activities can also drive the uptake of flood-resilience initiatives in existing communities, particularly for "lower cost" solutions that depend on homeowner participation and support.

To effectively prioritize these different approaches to mitigating flood risk, a flood hazard and vulnerability screening framework can help identify areas in existing residential communities that require the most immediate attention. Drawing on extensive engagement with key stakeholders across Canada, this report outlines such a framework, consisting of the following key considerations:

- Age of development: in the absence of major retrofits, older areas in Canada (e.g., pre-1970's) are typically more flood-prone, compared to newly-built subdivisions;
- History of flooding: in absence of major retrofits, where municipal records (e.g., flood reports) indicate that repeated floods have occurred, these areas may be the most flood-prone;
- Design standards: areas where community design standards were less stringent (e.g., permitting development in the floodplain) are typically at a higher risk of flooding;
- Proximity to the floodplain: areas located closer to the floodplain are typically at a higher risk of flooding;
- Topography: lower-lying areas are typically at a higher risk of flooding;
- Land use changes and intensification rates: areas where significant urbanization and growth has occurred, and where natural capacity to absorb rain water has diminished (e.g., as a result of losing permeable areas to development), are at a higher risk of flooding;
- Sewer system types: areas with combined sewer systems (CSS) (e.g., systems that carry sanitary and storm water in one pipe), or partially-separated sewers, compared to fully separated systems, are typically more flood prone; and
- Presence of critical infrastructure, essential services and social vulnerabilities: each of these criteria would prompt more urgent response to the identified flood-hazard areas.

Application of the framework will enable communities to make better-informed decisions when prioritizing areas for flood-resiliency programming. The purpose of the report is to serve as a seed document for a future National Standard of Canada, to be developed based on this framework.

Guidance in this report has been well-vetted, as it draws heavily on the insights of municipal planners, engineers, consultants, conservation authorities, developers,homebuilders, insurance industry representatives and stakeholders across Canada.

The report was supported financially and technically by the Standards Council of Canada (SCC) and the National Research Council (NRC), in response to commitments made by Canada as a signatory to the *Paris Agreement*[1], the United Nations' *Sendai Framework for Disaster Risk Reduction* (DRR)[2], and in support of the Pan-Canadian Framework on Clean Growth and Climate Change. Consistent with the intent of these international and national commitments, this report serves to help Canadians weather not only the storms of today, but to also ensure a more flood-resilient and climate-ready tomorrow.

Table 1: Examples of Flood Risk Reduction Approaches, by Types of Flooding (Residential Communities, Canada)

Types of Flooding	Examples of Flood Risk Reduction Approaches
Riverine flooding (also known as fluvial flooding) Occurs when water levels in watercourses rise and spill over their banks. Riverine flooding can be caused by extreme rainfall, snowmelt, ice build-up and debris jams.	• Proactive maintenance of culverts, bridges and other flood control structures; • Proactive vegetation management along watercourses, including debris removal; and • Flood-proofing properties adjacent to watercourses (e.g., through installing floodwalls and berms, re-grading lots and encouraging homeowners to elevate electrical equipment above potential flood levels).
Overland flooding (also known as pluvial flooding) Occurs when excess stormwater flows over private properties, entering homes through lowest building openings (e.g., basement windows and doors) causing damage.	• Proactive clearing of catch basins and culverts to allow overland water to drain; • Removal of snow from critical overland flow paths prior to spring thaw to prevent overland flow obstructions; • Re-grading of lots and roadways to carry overland water away from properties, onto the right of ways; and • Introducing additional storage facilities (e.g., through stormwater ponds, underground tanks, etc.) to store rainwater and reduce overland flow.
Storm and/or sanitary sewer back-up* Occurs when the storm and/or sanitary sewer systems are overloaded, causing surcharge and back-up into basements.	• Installing backwater valves (i.e., backflow prevention devices) on storm and/or sanitary sewer laterals to prevent surcharging sewer water from entering basements; • Disconnecting roof leaders from sanitary sewers; • Sealing and bolting manhole covers in low lying areas, where water accumulates and has a higher risk of contributing to sewer surcharge; and • Implementing stormwater diversion projects (e.g., through installing pipes that carry excess stormwater from overwhelmed areas to areas with more capacity).
Foundation system failures* Occurs when foundation drainage systems fail and water enters basements though foundation drains / seeps through the foundation walls.	• Installing sump pumps and sump pump back-up systems; and • Installing impermeable layer of soil around homes (i.e. foundation backfill areas) to reduce the risk of water infiltration and seepage through foundation walls

**Please refer to CSA Group's Guideline on Basement Flood Protection and Risk Reduction (CSA- Z800-18) for a comprehensive list of best practices to address storm and sanitary sewer back-up, and foundation system failure risks.*

CHAPTER 1: INTRODUCTION – THE NEED FOR CLIMATE ADAPTATION IN CANADA

Climate change and extreme weather events are on the rise in Canada, bringing ever-increasing costs to governments, businesses, and ultimately all Canadians.[3] In the past decade, flooding has emerged as the most pervasive and costly natural disaster in the country, causing financial and mental distress to Canadians across many regions. To limit the impacts of flooding, all levels of government (federal, provincial, territorial, municipal and Indigenous governments) are making new infrastructure investments and implementing flood risk reduction strategies.

This report outlines approaches that can be deployed by municipalities, utilities and local agencies (e.g., watershed managers such as conservation authorities in Ontario) to reduce flood risk for existing residential communities in Canada.[i]

The report is organized as follows:

- Chapter 1 examines the need for climate adaptation, particularly flood risk reduction, at the level of existing residential communities in Canada;
- Chapter 2 outlines common challenges pertaining to riverine flooding, overland flooding, storm and sanitary sewer back-up, and foundation system failures that can lead to basement flooding;
- Chapter 3 proposes a high-level screening framework for selecting areas within communities where flood risk reduction work should be prioritized;
- Chapter 4 outlines some approaches that can be deployed by municipalities, utilities and local agencies to reduce flood risk in Canada; and
- Chapter 5 provides concluding remarks and next steps.

The report also includes a summary of key updates made to the National Building Code since 1941 that impact the flood-resilience of residential buildings (Appendix A), as well as seven case studies of physical interventions that have been implemented in residential communities across Canada (Appendix B).

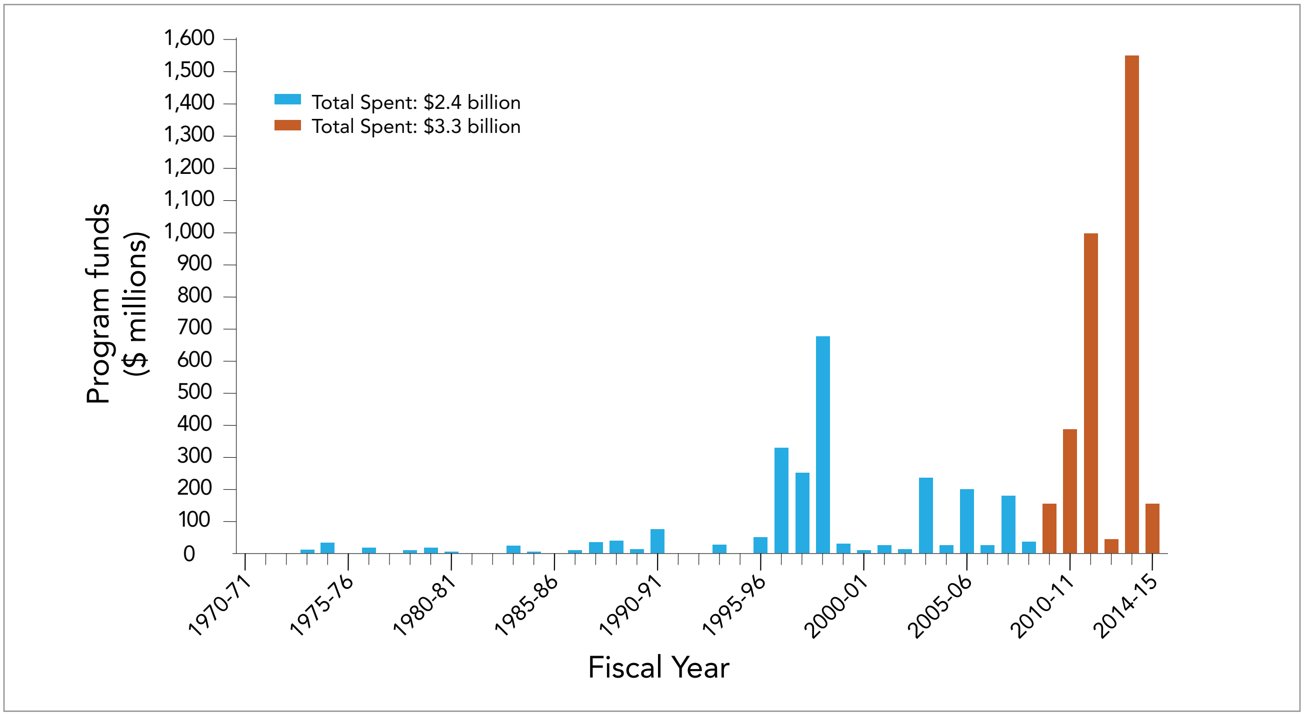
1.1 Escalating Costs of Natural Disasters and Flooding in Canada

Climate-related natural catastrophes and associated economic losses are expected to continue increasing in coming years. The Intergovernmental Panel on Climate Change (IPCC) projects continued global warming and increased global frequency of heavy precipitation events in the 21st century,[4] with Canada to warm faster than the global average and experience more frequent and severe weather.[5] Similarly, Environment and Climate Change Canada (ECCC) predicts growth in the frequency and severity of extreme weather events in Canada.[6] For example, a recent study by the Fraser Basin Council states that if there was a major flood event (1-in-500 year) in British Columbia's Lower Mainland between now and 2100, it would trigger economic losses estimated between $20 to 30 billion, which would be the largest disaster in Canadian history.[7]

The projected trends in climate related catastrophes are already manifesting themselves and present a significant economic concern. According to Public Safety Canada, the number of natural disasters for which provinces and territories required and obtained federal assistance under the Disaster Financial Assistance Arrangements (DFAA), increased dramatically between 1970 and 2015. Similarly, the Office of the Auditor General of Canada noted that from 2009 to 2015,[8] DFAA's compensation to provinces and territories was greater than all of the previous 39 fiscal years combined (see Figure 1).[9] The DFAA's spending on flooding was estimated at 75% of all weather-related expenditures.[10]

i For insights into approaches for building new residential communities in Canada that are more flood-resilient, please refer to the Intact Centre report, Preventing Disaster before It Strikes: Developing a Canadian Standard for Flood-Resilient Residential Communities , which is being developed into a national standard of Canada (CSA-W1006). Guidance on actions that can be implemented at the level of individual homes to reduce flood risk is available through the CSA Group Guideline on basement flood protection and risk reduction (CSA- Z800-18).

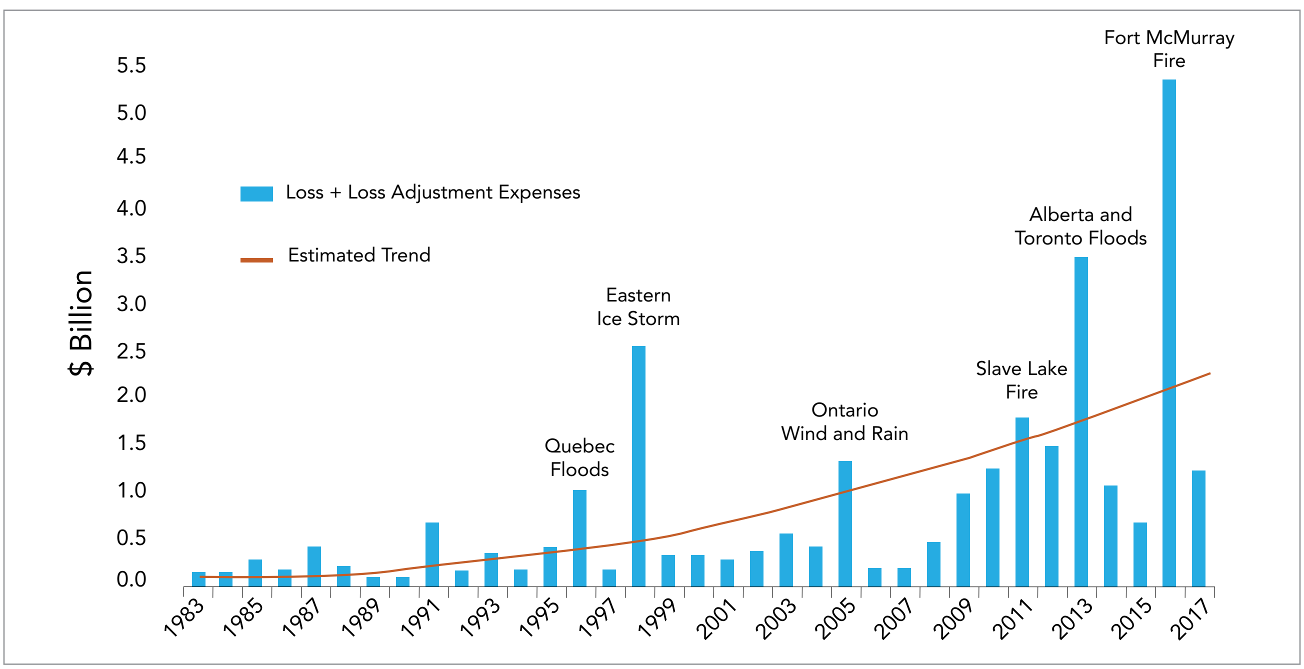
Figure 1: Disaster Financial Assistance Arrangements Program Spending, $CAD, 1970–2015



Source: Office of the Auditor General of Canada. 2016. Report 2: Mitigating the Impacts of Severe Weather.

The Insurance Bureau of Canada (IBC) found that "property and casualty (P&C) insurance payouts from extreme weather have more than doubled every five to 10 years since the 1980s."[11] While P&C insurance payouts in Canada averaged $405 million per year over the period of 1983 to 2008, for the last nine years leading up to 2017, insurance payouts for catastrophic losses averaged at $1.8 billion per year. Water-related losses were a significant driver in the increased payouts, explaining over 50% of the increase. The insurance gap in Canada is also significant: for every dollar insured of losses borne by insurers in Canada, three to four dollars are borne by governments and home and business owners.

Figure 2: Catastrophic Insured Losses in Canada (1983 – 2017)



Source: IBC Facts Book, PCS, CatIQ, Swiss Re, Munich Re & Deloitte.
**Values in 2017$ CAN, 2017; total natural catastrophe losses normalized by inflation and per-capita wealth accumulation*

1.2 Repeated Flooding Stresses Canada's Mortgage Holders

Approximately 1.7 million Canadian households, or 19% of Canada's population, are at risk of riverine and/or overland flooding.[ii] For areas where flood insurance coverage is limited or not available, and where Canadians are at the highest risk of flooding, this represents a significant economic concern. Flood damages can cost homeowners tens of thousands of dollars to repair. For example, the average flood damage costs for impacted homeowners in the Greater Toronto Area is estimated at $43,000.[iii] Meanwhile, as of 2017, the Canadian Payroll Association reported that almost half of working Canadians live paycheque to paycheque, with 47% indicating difficulty to meet financial obligations if their paycheques were delayed by a week.[12] Consequently, there is an emerging risk facing Canada's mortgage market, where flood-related mortgage arrears may become more frequent following flood events, as saving rates remain low and more households are subject to repeated flooding. Furthermore, flood-prone areas may become stigmatized, which further drives down property values in these areas, potentially below the outstanding mortgage balance.

1.3 Climate Risk and Flooding Impact Credit Ratings

Global credit rating agencies, including DBRS, Moody's and Standard & Poor's are beginning to examine climate change risks and potential impacts on ratings of tradable assets, including municipal bonds.[13] The Carbon Disclosure Project (CDP) predicts that tax base, debt levels and management quality are the three main areas, which credit rating analysis for municipal bonds will start to incorporate to determine how well municipalities are addressing climate risks.[14] In November 2017 Moody's Investors Service, (the bond credit rating dimension of Moody's Corporation), outlined four key credit risks associated with climate change that Moody's credit rating analysts look at when examining local and state government risks:

1. Economic disruption (e.g., property loss/damage; lower revenues; business interruption; increased debt; and higher insurance costs);
2. Physical damage (e.g., property loss/damage; loss of utilities, transportation and communication networks);
3. Health and public safety (e.g., loss of life, mental distress, jeopardized critical emergency service provisions); and
4. Population displacement (e.g., short-term displacements and longer-term population migration).[15]

Notably, flood risks comprise a significant focus for climate risk assessment metrics for Moody's, where points two, three, four and five below relate to flood risk:

1. GDP Coastal Counties/Total State GDP, 2016;
2. Tropical Cyclone Damage (1980–2017)/State GDP, 2016;
3. Coastal Dwelling Units in 100/500 Year Floodplains/ Total Coastal Dwelling Units;
4. Damage from Non-Tropical Cyclone Weather Events (1980-2017)/State GDP, 2016;
5. Non-Coastal Dwelling Units in 100/500 Year Floodplains/Total Non-Coastal Dwelling Units; and
6. Agricultural, Forestry, Fishing and Hunting/Total State GDP, 2016.[16]

In Canada, where flooding is the most common extreme weather risk facing municipalities, the focus of credit rating analysis for municipal bonds will undoubtedly reflect the initiatives deployed by local governments to improve their flood-resiliency. Measures to mitigate physical exposure to climate risks will weigh heavily in credit ratings.[17]

1.4 Flooding Gives Rise to Lawsuits

Flood-related lawsuits involving homeowners, developers, local governments, watershed managers (i.e. conservation authorities), Indigenous communities, provinces, and private businesses, are on the rise in Canada. Table 2 provides some examples of these lawsuits, demonstrating the need for flood-resilience at all levels of government, as well as business and society to limit legal risks.

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ii IBC commissioned analysis of fluvial and pluvial residential flood risk for Canada based on 2015 residential housing stock excluding apartment buildings and condominiums.
iii IBC estimates based on Toronto flooding in July 2013.

Table 2: Examples of Stormwater Management and Flood-Related Lawsuits in Canada

Case Name (year)	Description (damages, cost and settlement amounts included where identified)	Defendants
Anderson et al v Manitoba et al, 2017 (ongoing) Manitoba	A $950 million class action lawsuit was brought forward by 4,000 residents of four First Nations following severe flooding in the spring of 2011. A flood resulted in damage to property and the evacuation of many people from their homes. Plaintiffs brought claims of negligence, nuisance and breach of treaty rights, alleging that the Government of Manitoba caused the flooding through its operation of flood control measures and the water control works that affected the water levels around the four First Nations. The class action lawsuit was certified in January 2017 and is moving forward.	Province, Association of Native Fire Fighters Inc.
Muskoka Class Action, 2016 (ongoing) Ontario	Muskoka residents, cottage owners and business owners launched a $900 million class action lawsuit against the province of Ontario after damages caused by flooding and high water levels. Plaintiffs allege that the Ministry of Natural Resources was negligent for failing to control water levels. The claim is ongoing.	Province
Cerra et al. v. The Corporation of the City of Thunder Bay, 2012 (ongoing) Ontario	Floods in May 2012 resulted in severe damage in Thunder Bay, Ontario. Plaintiffs allege negligence in repair, inspection, and maintenance of the water pollution control plant, as well as lack of diligent operation and supervision at the time of the flood (including an allegation that alarms were ignored). The $300 million claim is ongoing. The court certified action on consent in 2013.	Municipality
Maple Ridge Class Action, 2010[18] (ongoing) British Columbia	Fifteen households filed a class action lawsuit against a developer and contractor, two engineering firms and the City of Maple Ridge after a 2010 flood. Plaintiffs allege that defendants were negligent, arguing construction failure, faulty workmanship and design, failure to inspect basements for leaks and failure to repair leaks as requested. Plaintiffs also argue that the houses were not waterproofed to code, despite the municipality's inspection, review and issuance of permits. The trial was scheduled to begin in 2016. The claim is ongoing.	Municipality, developer, contractor, engineering firms
Panza et al v. The Corporation of the City of Mississauga et al., 2012 Ontario	Upper and lower tier municipalities, the province and the conservation authority were all named as defendants in a negligence claim related to systemic flooding in the Lisgar area of Mississauga over several years. The $200 million action was withdrawn before trial. However, this case shows the potential for systemic flooding to give rise to class action lawsuits.	Province, municipality, conservation authority
Dicaire v. Chambly, 2008 Quebec	The Quebec Court of Appeal dismissed a class action by owners of 1,723 homes that flooded in 1997 when sewers backed up following heavy rains. The court ruled that the sewers were designed to withstand a "5-year storm" as provincial guidelines required, and the town was not obliged to do more. However, the court noted that current design standards might not protect municipalities in future lawsuits, in light of "recent climate phenomena" and other scientific advances.	Municipality
McLaren v. Stratford (City), 2005 Ontario	A major flood in the City of Stratford after severe rainfall in 2002 left many with sewage in their basements. Plaintiffs claimed negligence in design, construction, operation, and maintenance of the system. The class action was certified by the court in 2005 and the case was settled in 2010, eight years after the flood. Stratford settled for $7.7 million after already spending $1.3 million in emergency relief, and then upgraded the system to a 250-year storm standard.	Municipality

Source: Zizzo Strategy. 2017. Legal Risks and Requirements to Address Flood-Resilience. Prepared for the Intact Centre on Climate Adaptation.

1.5 Flooding Impacts the Mental Health of Canadians

Mental health impacts, associated with flooding, can include general mental distress, anxiety, post-traumatic stress disorder (PTSD), and depression. Mental distress is defined as "sufficient intensity to disrupt a person's normal life patterns."[19]

In Canada, several studies have found that Canadians have experienced mental distress because of flooding both in the immediate term and over the long term:

- A 2017 study of 200 households in Montreal that experienced flooding found that "almost 70% of respondents reported having suffered from anxiety, sleep disturbances or concentration problems since the floods;"[20]
- A 2004 study of 176 households in Manitoba found that over a third experienced psychological distress following a major flood event;[21]
- A 2016 study of men and women affected by the 2013 Alberta floods found a 164% increase in anti-anxiety medication and a 232% increase in sleeping aids for women in High River, one of the worst-hit areas;[22] and
- A 2000 study of Saguenay-Lac-St-Jean residents following 1996 floods found that 12% had to take sick leave or were absent from work, and 6% took an early retirement.[23]

Findings from an Intact Centre study of 100 households in flood-affected neighbourhoods in Southern Ontario (2018) confirm this finding of mental distress. Notably, three years after living through a flood, nearly 50% of households are "significantly worried" about flooding when it rains. Furthermore, homeowners who experienced basement flooding had to take, on average, seven days off work following the flood event.[24]

Robert Deeks

CHAPTER 2: CHARACTERIZATION OF COMMON FLOOD RISK CHALLENGES IN CANADA

This section outlines common flood risk challenges in Canada as related to riverine flooding, overland flooding, storm and sanitary sewer back-up and foundation drainage system failures. The challenges range from information limitations to guide adequate planning and land use management decisions, to physical conditions such as aging infrastructure and lack of infrastructure maintenance.

One crosscutting challenge is that stormwater infrastructure (Table 3) is designed to accommodate certain prescribed runoff levels associated with rainfall events (i.e. design storms), which are determined based on historical rainfall records. However, if precipitation patterns change over time (e.g., due to climate change), the historical designs based on probabilistic models that worked in the past, may not be adequate in the future. For example, as the global concentration of carbon dioxide in the atmosphere increases, the average air temperature is expected to increase as well, causing the hydrologic cycle to become more active. Increasing air temperature accelerates evaporation rates, which in turn feeds storm systems and may cause more frequent and severe rainfall events.[25]

Table 3: Stormwater Infrastructure (Examples)

Urban Stormwater Management	River Flood Management
• roadside ditches; • stormwater pipes/drains and sewer pipes; • manholes; • inlets and catch basins; • inlet control devices; • culverts and culvert grates; • control gates; • outfalls; • overland flow routes; and • stormwater management flood control systems (e.g., ponds and storage chambers).	• watercourses (e.g., rivers, creeks, streams, channels); • bank protection (e.g., lining, revetment); • hydraulic structures (e.g., bridges and culverts) • flood control structures and barriers (e.g., dikes, walls, diversions); and • flood control systems (e.g., dams, reservoirs).

In the following subsections, the challenges pertaining to riverine flooding, overland flooding, storm and sanitary sewer back-up, as well as foundation drainage system failures are described separately. However, it is important to acknowledge that flooding mechanisms are interrelated and often interdependent. During extreme events this interrelated nature of flood causes can lead to compounding flood risks and thereby result in greater flood damages.

Moreover, inter-jurisdictional watershed management practices can also influence flood risk and can lead to issues where land use changes in upstream jurisdictions can increase flood risks in the downstream jurisdictions. For example, in Manitoba, the communities of Brandon, Winnipeg and The Pas have all experienced elevated flood risks due to certain agricultural land use practices across upstream areas of Saskatchewan, Alberta and the USA. Therefore, coordinating inter-jurisdictional plans and watershed-based studies is important to mitigate potential increases in flood risk for downstream jurisdictions. Notably, this requires large-scale watershed-based analyses. An example of such inter-jurisdictional coordination is the Red River Basin Commission[26], which oversees the management and flood risk reduction activities for Red River (which flows through South and North Dakota, Minnesota and Southern Manitoba).

2.1 Riverine Flooding

For the purposes of this document, riverine flooding[iv] is defined as excess stream flow in a watercourse, such that land outside of the normal river banks is submerged or inundated. Riverine flooding can be caused or exacerbated by extreme rainfall, snowmelt, physical conditions (e.g., ice, sediment and debris jams, watercourse configuration changes and capacity limitations).

Common Challenges:

1. Lack of up-to-date floodplain maps, which take into account changes in climate, land use and development, as well as naturally-occurring changes in watercourses and floodplain conditions that were not anticipated in the original community design.
2. Legacy floodplain encroachment, where existing development is located in, or in close proximity to, the floodplain.
3. Ice, sediment and debris jams.
4. Inadequate design standards for flood protection infrastructure (e.g., dikes and floodwalls) to withstand extreme weather events.
5. Financial and technical challenges to retrofit existing flood protection infrastructure to meet contemporary design standards.
6. Deteriorated and/or aging riverine flood protection infrastructure (e.g. flood walls and reservoirs).
7. Undersized watercourse crossings (e.g., bridges, culverts and piped conveyance systems) including those that are prone to debris build-up, ice jams, scouring and deposition.
8. Long-term reliance on temporary riverine flood-protection measures, which were not intended or designed as permanent measures to address riverine flood risk.

2.2 Overland Flooding

For the purposes of this document, overland flooding is defined as flooding that occurs when urban runoff exceeds the combined hydraulic capacity of the area's storm sewers, ditches and catch basins, causing excess water to flow on the streets and then onto, between, and across residential properties. Overland flooding can happen anywhere in the community.

In cold weather climates, the compounded impacts of "rain on snow" events, frozen ground, obstructed overland flow paths (e.g., roads and ditches filled with ice and snow), as well as frozen culverts, catch basin inlets and leads - can all further exacerbate overland flooding.

Common Challenges:

1. Physical limitations in overland drainage due to poor grading and legacy development practices (e.g., pre 1980's, when the streets and rights-of-way were not explicitly designed to convey excess runoff by way of gravity away from private properties).
2. Low-lying areas tend to be at a higher risk of overland flooding due to runoff accumulation in these areas.
3. Increased imperviousness over time, which contributes to increased volumes and rates of stormwater runoff not accounted for in the original design of stormwater infrastructure.[v]
4. Culvert grates, inlets and catch basins not designed to contemporary standards (e.g., older stormwater inlet systems are often prone to blockage and thus convey less runoff than designed, leading to more runoff flowing overland).
5. Culvert grates, inlets and catch basins not regularly maintained and cleaned.
6. Reverse slope driveways and lot grading practices, whereby the overland stormwater runoff can flow towards homes, as opposed to away from homes, along the roadways.
7. Obstruction of overland drainage routes due to lack of maintenance or land alterations.
8. Obstruction of storm sewers due to poor maintenance.
9. Sedimentation and infilling of roadside ditches; blocked driveway culverts.

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iv Riverine water levels fluctuate naturally. Flooding, causing property damage typically occurs during events exceeding 5-year events, which commonly overtop watercourse banks.
v Increased imperviousness can occur both on private and public land through infill development, intensification, construction of new roads and parking lots, driveway widening and house expansions.

2.3 Storm and Sanitary Sewer Back-Up Flooding

For the purposes of this document, four distinct sewer systems types are considered:

- **Storm sewer back-up** occurs when storm sewers are blocked or overloaded by stormwater runoff, causing surcharge and back-up into homes through storm sewer laterals connected to the foundation drain system. As well, high water levels in storm sewers can prevent adequate foundation drainage, leading to basement flooding through foundation wall infiltration and seepage.[vi]
- **Sanitary sewer back-up** occurs when sanitary sewers are blocked or overloaded through inflow and infiltration, preventing sanitary effluent to be properly conveyed away from home to the sanitary sewer.
- **Combined sewer back-up** occurs when combined sewer systems (whereby storm and sanitary are conveyed in a common pipe) are blocked or overloaded by stormwater runoff, preventing sanitary effluent to be properly conveyed away from home to the combined sewer, or reverse flow from the sewer main to the home.
- Sewer systems can be also **partially separated**, whereby a stand-alone storm sewer system was built to collect surface runoff and provide relief for combined sewer systems.

Notably, the development of basements into living spaces, especially in older homes, increases sewer back-up damages and associated costs.

Common Challenges:

1. Storm sewer design capacity limitations in older neighborhoods (e.g., storm sewer systems designed for low intensity events, without consideration of dual drainage).
2. Infiltration of groundwater into sanitary sewers through aging or defective pipes, pipe joints, and leaky manholes.
3. Inflow into sanitary sewers from foundation drains, downspouts, roof leaders, manhole lids, and cross-connections (e.g., from catch basins and storm laterals).
4. Low-lying areas have a higher risk of sewer surcharge due to standing water that accumulates above manholes after a flood event, increasing risk of inflow into the sewer.
5. Sediment and other build-up in sanitary sewer pipes (e.g., silt, sand, debris, fat, oil, grease, sanitary products and other detritus) that reduces sewer capacity overtime.
6. Deteriorated structural condition of storm and sanitary sewer pipes (e.g., sags forming in pipes can cause sediment build-up and reduce sewer capacity; partial pipe collapses that can increase inflow into sewers and lead to sink holes).
7. High water levels in receiving waterbodies (e.g., rivers, creeks and lakes) can reduce the ability of storm and combined sewer systems to drain effectively.
8. Failures of wastewater treatment plants and pumping stations (e.g., during extreme rain events) that can cause both storm and sanitary sewer back-up.

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vi Storm sewers can also back-up to surface through catch basins, manholes, culvert inlets and ditch inlets, contributing to overland flooding.

2.4 Foundation Drainage System Failures

There are three basic foundation drainage approaches[vii]:

1. Sump Pump System: a mechanical system, which has a sump pit to collect foundation drainage from the home's weeping tiles. Once the sump pit fills to a prescribed level, the water is pumped by a small pump to the surface, where it is typically discharged directly to the surface flowing away from the home. In locations where the lawn space is constrained, the water can be discharged into a shallow lateral pipe and then into a storm sewer, ditch or a catch basin. Historically, sump pump systems were installed in areas with limited depth to drain foundation by gravity to a storm sewer. Since the mid-1990's sump pump systems have become more common in Canada as their reliability has improved.
2. Gravity Drain Systems - Connected to a Storm Sewer: systems where foundation water is collected around basement footings by weeping tiles and then conveyed through a lateral to the storm sewer, flowing by gravity. For this to be a viable drainage approach, the storm sewer needs to be deeper than the basement (usually 2.4 meters below the road centerline) and typically the hydraulic grade line for a prescribed event (e.g., a 1-in-100 year storm) is also below the basement foundation level.
3. Gravity Drain Systems - Connected to a Foundation Drain Collector: in some areas, where storm sewers are shallow and sump pumps have not been used to provide foundation drainage, foundation drainage is conveyed similar to Approach #2, however rather than discharging to the storm sewer, it is conveyed through a lateral to a dedicated foundation drain collector (FDC) system. This pipe eventually discharges to a waterbody or deep storm sewer typically located a significant distance downstream.

Common Challenges:

1. Where a direct gravity connection exists between the storm sewer and basement foundation drain (Approach #2), surcharged storm sewers can lead to basement flooding through water back-up and associated foundation wall seepage.
2. Poor backfilling practices (e.g., where soil was not properly compacted) can cause surface water to infiltrate more quickly - and in large amounts - to the weeping tiles overwhelming them and causing basement flooding.
3. Older homes (e.g., 80 years+) often lack appropriate foundation drainage systems like weeping tiles, or sump pump systems, or these systems have deteriorated beyond their reasonable life, causing foundation drainage water to accumulate around the basement footing and walls, seeping into the basement.
4. Lack of, or inadequate back-up power for, sump pump systems, which may cause flooding during power supply disruptions.
5. Homes located within areas with high groundwater levels can be exposed to a greater flood risk, as the system's capacity is consumed by both groundwater and other foundation drain sources (e.g., rain and snowmelt).
6. Homes built in areas where more permeable soil is underlain by an aquitard (solid, impermeable area underlying or overlying an aquifer) are especially susceptible to foundation seepage problems, as the upper soils allow the water to move downward quickly, while the lower aquitard layer prevents this water from draining.
7. Unintended increase in groundwater elevations due to reduced usage of groundwater resources for industrial or municipal purposes, or due to infrastructure renewal (e.g., as old clay and concrete sewer pipes with leaking joints are replaced with new sealed pipes, the ability for pipes to informally accept groundwater is reduced, increasing groundwater levels and putting properties at risk of groundwater seepage).

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vii Modern-day home foundation drainage systems collect and convey water, which gathers around basement footings from both surface water and groundwater sources. Historically, other systems were used, for example where homes had gravity drain systems connected to the sanitary or combined sewer system and where weeping tiles around foundation walls were directed to the sanitary sewer laterals. This was a major source of inflow/infiltration and contributor to sewer back-up risk.

CHAPTER 3: FRAMEWORK FOR PRIORITIZING FLOOD-RESILIENCY WORK IN EXISTING RESIDENTIAL COMMUNITIES, CANADA

This chapter proposes a high-level screening framework for selecting areas within residential communities where flood risk reduction work should be prioritized. Contributions from Hiran Sandanayake, Senior Engineer, Water Resources, City of Ottawa and Robert Muir, Manager, Stormwater, Asset Management Department, City of Markham are acknowledged, whose inputs informed the early development of this framework[viii].

Table 4 illustrates a conceptual evolution of flood risk assessment, of which the proposed high-level screening framework is the first, "foundational" step (denoted in grey). Information requirements to execute the framework are detailed in Sections 3.1 and 3.2, on flood hazard and flood vulnerability requirements respectively.

As communities in Canada elect to study flood risk in more detail, information requirements grow in concert with the intended level of understanding of flood risk (e.g., "intermediate" and "advanced" assessment steps in Table 4). For insights relating to more advanced methods of flood risk assessment, several frameworks can be leveraged (e.g., Engineers Canada' *PIEVC Engineering Protocol*[27], APEGBC's *Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate in BC*[28] and the forthcoming flood risk assessment guidelines under the federal *Canadian Floodplain Mapping Guidelines Series*.)[29] Such assessments can be used to guide the selection and application of more technical solutions for flood risk reduction, while providing more refined insights of flood risk (e.g., property-level understanding of flood risk). Third-party flood risk assessments can also be used to complement municipal analyses, for example assessments conducted by the (re)insurance industry.

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viii Contributions as per personal communication relating to the development of the City of Ottawa "Flood Risk Profile" methodology; and Rob Muir's "Reducing Flood Risk from Flood Plain to Floor Drain" document accessible at: http://www.cityfloodmap.com/2018/02/reducing-flood-risk-from-flood-plain-to.html

Table 4: Flood Risk Assessment Scope and Information Requirements (Maturity Scale)

Foundational Flood Hazard Assessment	Intermediate Flood Hazard Assessment	Advanced Flood Hazard Assessment
• Age of development (pre 1970s, 1970-1990s, post 1990s) • History of flooding (based on reported flood issues) • Design standards • Proximity to the floodplain • Topography (low lying areas and localized sags) • Land use change (intensification rates) • Sewer system type (combined; partially-separated; fully-separated) • Type of foundation drainage systems	In addition to Foundational Information: • Hydrologic and hydraulic modelling (urban and riverine) for storms of various return periods and Regulatory events to inform flood risk mapping and flood damage assessment • Modelling accounts for changes in rainfall parameters due to climate change (peak intensity, volume and duration) • Modelling accounts for future land use and growth plans • Stormwater infrastructure condition assessments and associated rankings • Sanitary sewer system capacity analysis, including short-term flow and rainfall monitoring to determine infiltration and inflow (I&I) stresses in the sanitary sewers	In addition to Intermediate Information: • Long-term monitoring of storm and sanitary sewer system flows, riverine flows, rainfall depth/amounts, groundwater levels and wet weather responses • Detailed/discrete soil data to inform intelligent application of source control techniques (practices applied to reduce water runoff where it originates) • Documentation of storm and sanitary sewer cross-connections • Operational and Maintenance data, which are utilized to optimize maintenance and inspection programs to mitigate flood risks
Foundational Flood Vulnerability Assessment	**Intermediate Flood Vulnerability Assessment**	**Advanced Flood Vulnerability Assessment**
• Number of properties at risk of flooding • Number of critical infrastructure assets at risk of flooding • Density of vulnerable/high risk populations at risk of flooding	In addition to Foundational Information: • Assessment of critical infrastructure and essential service delivery impacts (e.g., emergency, health and transportation service provision) • Assessment of social impacts of flooding (e.g., vulnerable populations impacted)	In addition to Intermediate Information: • Assessment of environmental impacts of flooding (e.g., sewage overflows, riverbank erosion, etc.) • Assessment of broader economic impacts of flooding (e.g., lost work hours, business disruptions; etc.)

3.1 Foundational Flood Hazard Assessment

Table 5 summarizes criteria for screening areas within communities in terms of their potential for exposure to flood hazards. Each criteria can be assigned a score (e.g., Low: 1, Medium: 2, High: 3). As areas within communities are analyzed, scores can be assigned and tallied. The higher the absolute score for a particular area, the higher its exposure to flood hazards. Not all criteria are considered equal in terms of influencing flood hazard exposure. **Criteria that would typically merit greater weighting (i.e., more likely to result in flooding) are highlighted in grey.** It is expected that users of the flood hazard assessment framework below will determine their own weightings relating to each of the locally-relevant criteria, as reflective of their unique flood risks and stormwater management objectives and priorities. The subsequent sections explain each criterion in more detail.

Table 5: Exposure to Flood Hazard: High-Level Screening Criteria and Description

Criteria Score	Criteria Description
A. General Conditions	
1. Age of Development*	
Low	Post 1990's
Medium	Post 1970's, but pre 1990's
High	Pre 1970's
*Assuming no major retrofits were completed to improve the level of service in a given area	
2. History of Flooding	
Low	No or limited number of properties with flood reports history / no or limited times that temporary flood mitigation measures had to be initiated in the community to respond to flood-related emergencies
Medium	Some properties with flood reports history, approximately at a community average* / temporary flood mitigation measures have been occasionally initiated in the community to respond to flood-related emergencies
High	High density (i.e., "clusters") of properties with flood reports history, above community average* / temporary flood mitigation measures are regularly initiated in the community to respond to flood-related emergencies
*Community average can be calculated as the total number of homes with reported flood history divided by total number of homes in a community	
3. Flood Forecasting and Warning Systems	
Low	Flood forecasting and warning systems are in place and provide sufficient operational lead time to deploy flood protection measures in case of a flood emergency
Medium	Flood forecasting and warning systems are in place, however due to gauging density and/or watershed characteristics, the system has a reduced potential for accurate and timely response
High	Flood forecasting and warning systems are not in place
B. Riverine Flooding	
1. Regulatory Event Standard and Floodplain Mapping	
Low	Higher return period used as a design storm (e.g., 1-in-500 year). Floodplain maps are current and account for changes in climate, land use and development, as well as potential for naturally-occurring changes in watercourses and floodplain conditions
Medium	Floodplain mapping is available based on projected land uses, but is over 10 years old and does not consider climate change
High	Lower return period used as a design storm (e.g., 1-in-100 year or less). Floodplain maps are outdated (do not account for changes in climate, land use and development, as well as naturally-occurring changes in watercourses and floodplain conditions)

2. Proximity to the Floodplain	
Low	Dwellings, lots and right of way access are located outside of the current and climate-change-adjusted floodplain or protected by permanent engineered flood protection defenses (e.g., dikes, upsized culverts, channel diversions, etc.)
Medium	Dwellings are located outside of the current floodplain or protected by non-permanent engineered flood protection defenses (e.g., ponds, berms and dams), but lots and right of way access are partially within the current floodplain
High	Dwellings, lots and right of way access are located within the floodplain and are reliant on emergency flood protection measures (e.g., sandbags and temporary flood barriers)
C. Overland Flooding	
1. Topography	
Low	Average slopes of an urban drainage area exceed 1%
Medium	Average slopes of an urban drainage area less than 1% and no obvious depressions
High	Lower lying areas, with localized depressions and roadway sags
2. Land Use Intensification/Imperviousness	
Low	Community character is largely maintained as designed OR stormwater best management practices have been implemented in conjunction with transition in community character
Medium	Community character is transitioning to more impervious cover
High	Community character has transitioned to more impervious cover (e.g., larger homes and multi-family development)
D. Storm and Sanitary Sewer Back-Up Flooding	
1. Sewer System Type	
Low	Fully-separated sewer system.
Medium	Partially separated sewers or combined sewer systems, where combined sewer overflow is adequate and provides sufficient relief
High	Partially separated sewers or combined sewer systems, where combined sewer overflow is restricted and does not provide sufficient relief
2. Minor (Storm Sewer) System Design Standards	
Low	1-in-10 year standard or greater
Medium	1-in-5 year standard
High	1-in-2 year standard or less
3. Wastewater Pumping Station Design and Location	
Low	Wastewater pumping stations located in areas where they will remain fully-operational and accessible during extreme rain and riverine flood events
Medium	Wastewater pumping stations located in flood-prone areas OR not upgraded to contemporary standards
High	Wastewater pumping stations located in flood-prone areas AND not upgraded to contemporary standards AND do not have back-up power
E. Foundation Drainage System Failures	
1. Sump Pump System	
Low	Back-up power AND secondary sump pump
Medium	Back-up power OR secondary sump pump
High	No back-up power AND no secondary sump pump

2. Gravity Drain System - Connected to the Storm Sewer	
Low	Storm sewer modelling shows no basement flooding for a 100-year event, and is greater than 2.4 m below roadway
Medium	Storm sewer greater than 2.4 m below roadway centerline
High	Storm sewer less than 2.4 m below roadway centerline
3. Gravity Drain System - Connected to the Foundation Drain Collector	
Low	Low groundwater table with deep deposits of permeable soils
Medium	Seasonally high groundwater table, and variable and potentially high risk soil conditions
High	High groundwater table year-round, or permeable soils underlain by a relatively shallow aquitard

3.1.1 General Hazard Assessment Considerations

Age of Development

Since 1941, the National Building Code of Canada (NBC) sets technical provisions for design and construction of new buildings. The Provinces and Territories are responsible for establishing building codes within their jurisdictions and rely on the NBC for the national framework. With NBC updates taking place approximately every five years, it is possible to track the history of major flood-resiliency measures introduced in the code and consequently, their implementation across residential developments. While the extent and timing of NBC implementation varies across different jurisdictions in Canada, Appendix A outlines key flood-resiliency updates and timing to the code, which provides a starting point for flood risk screening based on the age of development.

Moreover, some key dates in the evolution of stormwater management in Canada can be used to draw further insights about potential flood risk challenges associated with "certain eras" of residential development (see Box 1).

Box 1: History of Stormwater Management in Canada: Four Key Eras

The Storm Sewer Era (1880-1970)

From approximately 1880-1970, the solution to the problem of increased volumes and flows of urban stormwater was the provision of a sewer network which transported stormwater from upstream urbanized areas to downstream receiving waters - creeks, rivers, lakes and oceans. Generally sanitary effluent was also conveyed through the same combined network, and these flows were discharged without treatment. Design criteria included prescribing a design rainfall input of specified return period, usually in the range of 2-10 years (occasionally up to 25 years), and a procedure (the Rational Method) for computing the peak flow resulting from this rainfall over a duration equal to the time of concentration. Pipes were sized to convey these peak flows. The benefits of the storm sewer solution included minimal local flooding except under extreme storm conditions. However, as urban areas grew significantly, the costs of large collector sewers and erosion control measures increased. Generally, the environmental cost of pollution in receiving waters was not recognized throughout most of the storm sewer era.

The Stormwater Management Era (1970-1990)

Through the 1970s and 1980s, increased volumes and flows were treated via two additional means: a) the insertion of stormwater storage facilities (i.e. ponds) within, or at, the downstream end of the storm sewer network and, b) in many but not all jurisdictions, explicit consideration of the major overland system to convey flows, which exceed the capacity of the minor system (pipes and ponds). New developments in this era generally had separated sanitary and storm systems. Design criteria included the prescription of a design storm input for each of the minor and major systems and a restriction on post-development flows - in general, these typically could not exceed pre-development flows under design storm conditions. Specified return periods were typically 2–10 years for the minor system and 100 years for the major system. Design procedures included the use of numerical urban runoff models with design storm inputs for computing the flow at any time and point in the system. Pipes and ponds were sized to convey and store these flows. Relative to the storm sewer era, stormwater management solutions minimized local and downstream flooding, reduced the cost of sewers in many cases and provided waterfront property around the stormwater ponds. However, long-term costs, including those for pond maintenance and erosion control downstream of the ponds, remained. Although pollution of receiving waters was generally recognized in this era, the cost was not explicitly considered in the design process.

The Urban Stormwater Best Management Practices Era (1990-2000)

Since the 1990's, concern over the residual problems associated with stormwater management, and deteriorating water quality including erosion, have led some jurisdictions into the urban stormwater best management practices (BMP) era. Early Canadian examples included the Cities of Edmonton, Winnipeg, Hamilton, Toronto, Ottawa and Montréal, and the Greater Vancouver Regional District (Marsalek 1999). This era is distinguished from the stormwater management period in that the problem was expanded to include the quality, as well as the quantity of stormwater. The solution is extended to include a wide range of urban stormwater BMPs such as extended detention ponds, infiltration basins and trenches, porous pavement, sand filters, water quality inlets and use of vegetation. Additional benefits of the BMP solution (over the stormwater management solution) include reduced erosion and improved water quality in receiving waters; however, these are offset somewhat by additional maintenance costs.

New Paradigms (2000-present)

The current era of stormwater management in Canada reflects the increasing sophistication of drainage management over time. It emphasizes the importance of flood control in the context of holistic watershed management and integrated urban water management. Drainage systems designs for this era often place emphasis on sustainability criteria and protection of ecological systems (e.g., through pollution reduction and erosion control). Some jurisdictions in Canada (e.g., the Province of British Columbia) have set out runoff volume control targets, prescribing methods for runoff retention and detention, as well as implemented hierarchical approaches to stormwater management, starting with source control at a lot level, followed by stormwater conveyance (e.g., via roads and public spaces), followed by end-of-pipe treatment prior to discharge.

Sources: Watt, W.E., D. Waters and R. McLean 2003. Climate Variability and Urban Stormwater Infrastructure in Canada: Context and Case Studies. Toronto-Niagara Region Study Report and Working Paper Series, Report 2003-1. Meteorological Service of Canada, Waterloo, Ontario.

Rivard, G., 2015. LID Implementation: From an international Perspective to a Canadian One: Synthesis of the SOCOMA (Source Control Management) Activities Specific Needs for Successful Projects in Canada. Presented at 4th Annual TRIECA Conference.

Rob Muir. CityFloodMap.com Blog, "Reducing Flood Risk from Flood Plain to Floor Drain" document accessible at: http://www.cityfloodmap.com/2018/02/reducing-flood-risk-from-flood-plain-to.html

History of Flooding

Municipal records indicating repeated flood complaints are helpful in identifying areas where flooding is a chronic problem. These records may also help characterize specific flood issues (e.g., the specific mechanism of flooding, extent, frequency, associated impacts).

Flood Forecasting and Warning Systems

Forecasting and warning of flood events is complex and traditionally relates to the domain of watershed managers. The key determinant in gauging the effectiveness of flood forecasting and warning systems relates to the amount of advance warning time. Where notices are provided sufficiently in advance to allow for orderly evacuations and/or timely implementation of flood defences, the flood forecasting and warning systems are deemed to operate well. In urban settings, it is more challenging to provide a meaningful notice of flood events (e.g., as compared to larger watersheds, with slower response times).

3.1.2 Riverine Flooding - Hazard Assessment Considerations

Regulatory Event Standard and Floodplain Mapping

Provinces and territories across Canada have historically applied different floodplain management regulations, typically prohibiting new residential development in the active portion of the floodplain (often referred to as the floodway) and restricting development in the flood fringe (the area outside of the floodway with slower and shallower flowing water). In some cases (often referred to as Two-Zone or Special Policy Areas), residential properties are subject to implementation of appropriate flood protection measures, if they are within the floodplain. Table 6 provides floodway and flood fringe definitions currently used in different parts of Canada. In general, the higher the return period used for regulatory flood definition, the lower the risk of riverine flooding.

The relative age, accuracy and extent of floodplain maps also plays a role in riverine flood risk (as discussed in Chapter 2). The first large-scale floodplain mapping effort in Canada took place in 1980s, under Canada's *Flood Damage Reduction Program* (FDRP). In some areas in Canada, subsequent updates to floodplain maps (post FDRP) have been limited. That said, there are still some urban areas, which were constructed long before formal flood plain mapping were developed, hence these existing residential communities can be at a higher risk of flooding.

*Table 6: Defining Regulatory Flood, Floodway and Flood Fringe for Riverine Flooding in Canada**

Provinces / Territories	Regulatory Flood	Definition of Floodway	Definition of Flood Fringe
British Columbia	1-in-200 years Plus an additional freeboard for hydrologic and hydraulic uncertainties or 1894 Flood of Record for Lower Fraser River	The channel of the watercourse and those portions of the floodplain, which are reasonably required to convey the designated flood. At minimum, the floodway is equal to the width of the channel within the natural boundary plus a minimum setback of 30 meters from the natural boundary on each side of the channel, or unless otherwise approved.	The portion of the floodplain not in the floodway to which flood-proofing requirements apply.
Alberta	1-in-100 years	The floodway includes areas where the water is one meter deep or greater, the local velocities are one meter per second or faster and if the river were encroached upon, the water level rise would be 0.3 meters or more.	The flood fringe is the land along the edges of the flood hazard area that has relatively shallow water (less than one meter deep) with lower velocities (less than one meter per second).
Saskatchewan	1-in-500 years Plus additional freeboard for hydrologic and hydraulic uncertainties	The portion of the floodplain adjoining the channel where the waters in the 1:500 year flood are projected to meet or exceed a depth of one meter or a velocity of one meter per second.	The portion of the floodplain where the waters in the 1:500 year flood are projected to be less than one meter deep, with velocity less than one meter per second.
Manitoba	1-in-100 years 1:700 for the City of Winnipeg	The portion of the floodplain where the depth of flooding is greater than one meter.	The remainder of the floodplain beyond the floodway.

Ontario	1-in-100 years OR Regional Storms (Hurricane Hazel or Timmins Storm), whichever is greater	Where the one zone concept is applied, the floodway is the entire floodplain. Where the two-zone concept is applied, the floodway is the inner portion of the floodplain, representing that area required for the safe passage of flood flow and/or that area where flood depths and/or velocities are considered to be such that they pose a potential threat to life and/or property damage.	The outer portion of the floodplain between the floodway and the flooding hazard limit.
Quebec	1-in-100 years	Part of the floodplain that may be flooded during a 20-year flood event.	Part of the floodplain beyond the high-velocity zone that may be flooded during a 1:100 year flood.
New Brunswick	1-in-100 years	Part of the floodplain that may be flooded during a 20-year flood event.	Part of the floodplain between the floodway and the outer limit of the flood risk area, whether it is the 1:100 year flood line or a higher historic flood line.
Nova Scotia	1-in-100 years	The inner portion of a flood risk area where the risk of flooding is greatest, on average once in 20 years and where flood depths and velocities are greatest.	The outer portion of a flood risk area, between the floodway and the outer boundary of the flood risk area, where the risk of flooding is lower or average 1:100 year, and floodwaters are shallower and slower flowing.
Newfoundland and Labrador	1-in-100 years, adjusted for Climate Change	The inner portion of a flood risk area where the risk of flooding is greatest, on average once in 20 years and where flood depths and velocities are greatest.	The outer portion of a flood risk area, between the floodway and the outer boundary of the flood risk area, where the risk of flooding is lower or average 1:100 year, and floodwaters are shallower and slower flowing.
North West Territories	1-in-100 years	The floodway includes areas where the water is one meter deep or greater, the local velocities are one meter per second or faster and if the river were encroached upon, the water level rise would be 0.3 meters or more.	The flood fringe is the land along the edges of the flood hazard area that has relatively shallow water (less than one meter deep) with lower velocities (less than one meter per second).
Nunavut	1-in-100 years	The floodway includes areas where the water is one meter deep or greater, the local velocities are one meter per second or faster, and if the river were encroached upon, the water level rise would be 0.3 meters or more.	The flood fringe is the land along the edges of the flood hazard area that has relatively shallow water (less than one meter deep) with lower velocities (less than one meter per second).

** Floodway and flood fringe definitions are not available for Prince Edward Island and Yukon.*

Proximity to the Floodplain

Residential developments that are in close proximity to, or partially or fully within, the Regulatory floodplain, or within spill zones from riverine systems, may be at higher risk of direct and indirect flooding during extreme weather events. However, it is also important to recognize that permanent and non-permanent flood protection defenses, such as diversions, dikes and dams, can mitigate the risk of riverine flooding. Therefore, as indicated in Table 5, where a jurisdiction considers flood protection defenses permanent (because they have been engineered to withstand extreme weather events and are properly maintained), then the riverine flood risk and associated regulation may be deemed reduced by that jurisdiction.

3.1.3 Overland Flooding - Hazard Assessment Considerations

Topography

Low-lying areas, particularly those prone to overland flow from comparatively large drainage areas, are at risk of surface flooding due to the tendency for these areas to accumulate runoff and pond, particularly in the absence of adequate outlets. There can also be a correlation to increased basement flooding through inflow to the sanitary system in low-lying areas.

These low-lying areas can cover many city blocks and may not be immediately evident until a major storm event has occurred. By way of example, reviews of historical basement flooding records in Edmonton, Alberta have shown a higher correlation of basement flooding occurring in these locations, which in some cases are the areas where old creek beds, lakes or slews used to be prior to subdivision development. High-level topographic mapping can provide an initial indicator of these locations for flood risk evaluations.


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Land Use Intensification/Imperviousness

Due to changing planning policies across Canada, which have the objective of reducing urban sprawl, increasing development efficiencies, and reducing infrastructure-servicing costs, many municipalities are increasing population densities within their urban limits. This approach, over time, leads to greater hard surface cover (e.g., buildings, parking lots and amenity areas). In addition, there is also a trend towards upsizing homes whereby, on larger lots, small homes are demolished and much larger homes, with impermeable landscaping, are built (or multi-family homes are introduced in place, where single-family homes used to be). This practice can contribute to higher volumes and rates of surface water runoff. Moreover, communities developed within, or in close proximity to, floodplains are often more desirable neighborhoods, where intensification occurs at a faster rate, exacerbating neighbourhood exposure to riverine flood risk.

3.1.4 Storm and Sanitary Sewer Back-Up Flooding - Hazard Assessment Considerations

Sewer System Type

As noted earlier, there are generally three types of sewer systems: combined (single pipe carrying day-to-day sanitary effluent and storm flows), separated (independent systems to convey sanitary and storm flows) and partially separated systems (combined systems in transition to separation). Typically, due to the operating nature of combined sewer systems, they have the highest risk of sanitary sewer back-up, since they surcharge quickly due to storm runoff capture. However, partially separated sewers or combined sewer systems, where combined sewer overflow is restricted and does not provide sufficient relief, can also present a high flood risk (e.g., in the City of St. Catharines, City of Montreal and City of Ottawa).

As sewer systems undergo retrofits, such as sewer separation projects for combined sewer areas, typically the public side becomes fully separated, but the private side may or may not be (e.g. downspouts, weeping tiles and private catch basins may completely or partially remain connected to the combined sewer); this can complicate flood investigations.

Minor (Storm Sewer) and Major (Overland) System Design Standards/ Level of Service (LOS) Assumptions

Design standards of storm and sanitary infrastructure can be used to gauge risk. For example, a storm sewer designed to a 2-year standard would have approximately a 50% chance of surcharging in any given year, whereas a storm sewer designed to a 10-year return period, would have a 10% chance of surcharging in any given year. The same would apply to overland flow systems (major system), whereby in some eras of development there was no acknowledgement of this part of the drainage system ("dual drainage" systems were not considered, hence overland flow was not designed to safely drain by gravity to a suitable outlet). Post 1980's, many jurisdictions adopted the dual drainage (major-minor) approach, and set standards for overland flow conveyance. Many municipalities use the 100-year standard (event that would on average have a 1% chance of occurrence in any given year) to design major overland systems. However, it is important to acknowledge that the risk that a 100-year flood happening at least once during a 25-year period is not 1% but 22% (and 40% for a 50-year period). The relationship between return period and the mean probability of occurrence per year is illustrated below (Table 7).

Table 7: Flood Risk Associated with Different Return Periods and Mean Probability of Occurrence per Year

Return period (years)	Mean probability of occurrence per year	Flood Risk for a Given Period of N Years				
		N = 100	N = 50	N = 25	N = 10	N = 1
100	1%	64%	40%	22%	10%	1%
50	2%	87%	64%	40%	18%	2%
25	4%	98%	87%	64%	34%	4%
10	10%	100%	99%	93%	65%	10%
5	20%	100%	100%	100%	89%	20%

Source: Adapted from Stormwater Management Guide, Ministry of Environment, Quebec, 2011.

Wastewater Pumping Station Design and Location

Wastewater pumping stations, if located within a riverine flood plain, or defined overland flow routes, can be at greater risk of failure due to flooding, power outages during extreme events and other operational issues. While most systems have built-in safety features (e.g., including relief overflows), even these can be prone to failure or reduced effectiveness during extreme weather events, exacerbating flood risk. Some pumping stations may be located in relatively remote areas, which can result in longer response times during emergency situations.

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3.1.5 Foundation Drain System Failures - Hazard Assessment Considerations

Sump Pump System

Sump pumps are mechanical devices which rely on power and working conditions to operate. In the absence of power, the systems fail and water begins to accumulate around foundation walls, increasing the risk of basement flooding. Similarly, if the pumps are not well-maintained or fail due to overuse, they can also result in basement flooding. Having a secondary (back-up) sump pump provides additional relief should the primary sump pump fail. Where sump pump discharge is to the surface, it must be directed away from the house to a location where it does not immediately return to the foundation. This can be an issue on small, poorly graded properties, or where discharge pipes are disconnected, blocked or frozen.

Gravity Drain Systems - Connected to the Storm Sewer

Where storm sewers are sufficiently deep (i.e., 2.4 m below roadway centerline), basement foundation drainage can be conveyed by gravity to the sewers directly. However, during large storms these sewers can surcharge, which will prevent basement water from being released into the sewer; or lead to a reverse flow from the storm sewer to the home. Under the most extreme conditions, sewer water flow can back-up into the basement through the foundation drainage system.

Gravity Drain Systems - Connected to the Foundation Drain Collector

Where storm sewers are too shallow and not serviced by sump pumps, a third pipe, referred to as a Foundation Drain Collector (FDC) can be used. In areas where the soils are highly permeable and the groundwater levels low, the chances of having external water enter the FDC is low; that said where groundwater levels are high and the FDC trench is founded on an aquitard, the chances of build-up of water around the FDC increases and so does the risk of basement water infiltration.

Areas with perennially or seasonally high ground water may also be susceptible to higher flood risk (e.g., storm and sanitary sewers can be influenced by inflow and infiltration due to high groundwater reducing available capacity, as well, foundation drains around homes can become overwhelmed during periods of high groundwater).

Robert Deeks

3.2 High-Level Flood Vulnerability Assessment

For areas that are deemed to be at an equal specified risk of flooding (using Table 5), the presence or absence of critical infrastructure, essential services and greater concentrations of vulnerable populations, can be used for further prioritization of flood risk reduction work. For the foundational flood risk assessment, in addition to the number of residential properties at risk of flooding, a measure of critical infrastructure assets at risk of flooding and the density of vulnerable/high risk populations at risk of flooding can be considered for priority setting.

3.2.1 Critical Infrastructure and Essential Services

According to Public Safety Canada, critical infrastructure refers to "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government."[30] Loss of critical infrastructure assets, or disruption to essential services, may have significant and adverse economic, social and environmental impacts within a community. Accordingly, the process of flood risk assessments and prioritization, needs to incorporate an analysis of critical infrastructure assets and essential services from the standpoint of consequence of loss[31]. Examples of critical infrastructure assets include: water, stormwater and wastewater treatment plants, pumping stations, utilities, transportation, and health care facilities. At the municipal level, essential services can typically include:

- Fire and police protection;
- Health care provision;
- Emergency response facilities and routes;
- Water treatment and distribution;
- Wastewater treatment and collection;
- Stormwater management and flood protection;
- Garbage and recycling collection;
- Public transportation;
- Maintenance of roads and sidewalks and streetlights.

Public opinion surveys can be used to prioritize critical infrastructure assets to protect from flooding. For example, EPCOR conducted a public opinion survey in 2018[32], which identified areas of higher priority to protect from flooding as per input from City of Edmonton residents, as follows:

1. Essential services: The highest priorities for flood protection were hospitals and urgent care facilities, as well as essential services such as fire, police, emergency response and essential utilities.
2. Social agencies: The next most important priorities for protection were agencies that protect population from risks to human life and that provide services and housing to vulnerable populations.
3. Recreation centers, shopping malls, transit stations, schools, universities/colleges.
4. Financial and environmental services: Financial and environmental impacts were ranked as less important. Impacts that were reversible, temporary or insurable are deemed to have lower relative importance.[33]

3.2.2 Vulnerable Populations

The Government of Canada acknowledges that the environment can affect health, and that some populations in Canada are more vulnerable to environmental risks as a result of physical differences, behaviours, location and/or control over their environment.[34] The Red Cross identifies the following ten populations in Canada as vulnerable (high-risk):

1. Seniors;
2. Persons with disability;
3. Indigenous residents;
4. Medically dependent persons;
5. Low-income residents;
6. Children and youth;
7. Persons with low literacy levels;
8. Women;
9. Transient populations; and
10. New immigrants and cultural minorities.[35]

The presence of select institutions, such as daycares, schools and nursing homes, where vulnerable populations may be concentrated, also needs to be factored into flood vulnerability analyses. Notably, some municipalities in Canada have created well-being indices, identifying locations with high concentrations of vulnerable populations, which can be helpful for flood vulnerability assessments.[36]

3.3 Application of the Framework for Prioritizing Flood-Resiliency Work in Existing Residential Communities: Case Study from Credit Valley Conservation, Ontario

Presented below is a case study from Credit Valley Conservation (CVC), demonstrating the utility of the framework described above. The case study was prepared by Christine Zimmer Senior Manager, Water and Climate Change Science, CVC, Amna Tariq, Engineer, Water and Climate Change Sciences, CVC, and Kamal Paudel, Senior Specialist, Data Management and Business Intelligence, CVC.

Stormwater management has evolved rapidly over the last 40 years, as reflected in the varied levels of service within most municipalities in Canada. Updating infrastructure to ensure appropriate levels of service comes at a significant financial cost. Municipalities need to identify high-priority areas and select the best measures to reduce these risks.

To assist in a more holistic understanding of flood risks, Credit Valley Conservation (CVC) and partner municipalities initiated a flood risk mapping exercise in the Credit Valley watershed in Ontario.

The first step was applying the screening method from the Intact Centre's 2018 Flood Hazard High-Level Screening Framework. As the level of geographic information system (GIS) information varied across the watershed, only the following layers from the framework were used, where available:

- Age of development within each dissemination area (a standard geographical unit used by Statistics Canada);
- History of flooding (flood complaints and location of reported flood damage);
- Proximity to the floodplain (including flood vulnerable structures); and
- Reported insurable losses.

The first step highlighted the threats to stormwater management infrastructure.

The second step was to consider the impacts to services and populations that are less resilient to flooding (shelters, schools, hospitals, and senior care facilities). To account for these social vulnerabilities, the following layers were added to the infrastructure vulnerability mapping:

- Vulnerable populations within each dissemination area (including children, seniors, and low-income renters);
- Medical centres/facilities;
- Utilities (including telecommunications);
- Emergency service infrastructure (including fire, police and medical services) and;
- Community facilities used for as emergency centres (including evacuation centres, community centres and schools).

The two steps of flood hazard and social vulnerability screening provided a sense of the potential flood prone areas for prioritizing flood mitigation measures.

A broader suite of considerations were also used to support watershed and stormwater master planning in the region (including drinking water supply, water quality, soil erosion, water balance, and overall public well-being). To reflect these considerations, CVC built on the Intact Centre's approach and included additional information to conduct further assessments:

- Locations of stormwater ponds/flood storage facilities;
- Locations with current and projected water quality issues;
- Locations with identified opportunities to implement green infrastructure solutions; and
- Groundwater table information.

After completing various steps of the assessment, CVC found that certain layers influence the outcomes of the assessment in unique ways, and need to be weighted accordingly. CVC is now performing sensitivity analyses across the watershed, taking into account the different needs of each municipality. Weighting criteria will be ranked according to the specific risks facing each community. For example, maintaining baseflow and groundwater quality may be critical to groundwater-dependent municipalities, while established lake-based municipalities may prioritize flood risk reduction, erosion and water quality control. Municipal partners have been engaged across a range of departments, including health, planning, emergency and water management.

Mapping will be used to identify areas where further research is needed to understand flood vulnerabilities and select the best management practices to reduce them.

CHAPTER 4: APPROACHES TO FLOOD RISK REDUCTION IN EXISTING RESIDENTIAL COMMUNITIES, CANADA

This chapter outlines some approaches to flood risk reduction, which can be implemented by municipalities and local government agencies within existing residential communities. Table 8 outlines the scope of these best practices.

Table 8: Scope of Best Practices for Flood Risk Reduction

In Scope	Out of Scope
Approaches: • Flood risk reduction guidance • Operations and maintenance programs • Public engagement • Selected physical interventions to reduce flood risk	Approaches: • Lot-level (private side) improvements, as these are covered through CSA Group Guideline on basement flood protection and risk reduction (CSA- Z800-18) • Approaches pertaining to Emergency Planning and Response as the document focuses on flood prevention
Geography: • Canadian communities located below the 60th parallel north (i.e., southern communities)	Geography: • Permafrost communities
Flood Hazards: • Riverine • Overland • Storm and sanitary sewer back-up • Foundation drainage system failures	Flood Hazards: • Storm surge, tidal flooding and sea level rise • Unique flood hazards (e.g., dam failures, tsunami, etc.)
Development Type: • Urban and suburban residential developments* • Mixed-use development (e.g., residential and commercial)	Development Type: • Non-residential developments (e.g., solely industrial, commercial and institutional land, agricultural land, and major transportation routes)

** Although many best practices will also apply to rural residential developments.*

As noted in Table 8, approaches pertaining to emergency planning and response are outside of the scope of this report, as it is focused primarily on flood prevention. However, stakeholders suggested that future research is warranted in this space. Similarly, stakeholders suggested there is a need for more in-depth research relating to operations and maintenance (O&M) activities for stormwater and river management infrastructure.

4.1 Flood Risk Reduction Guidance

Below is a list of approaches that relate to flood risk reduction guidance that communities across Canada may wish to adopt going forward to increase their flood-resiliency:

1. Develop and regularly update flood risk assessments, which address all flood hazards to provide direction for infrastructure renewal, community redevelopment and intensification.
2. Regularly review design storms and Intensity, Duration and Frequency (IDF) curves to ensure they are representative of the current climate.
3. Ensure that official plans, municipal guidelines and regulations stipulate that new development, intensification and re-development plans reduce, or at least do not increase, the risk of flooding for existing communities.
4. Ensure that official plans, zoning by-laws and regulations restrict alterations to properties located in high flood risk areas that could increase flood damages (e.g., in high flood risk areas, prohibit construction of new walkout basements, use of basements as living spaces and increases in impermeable landscaping).
5. Ensure that regulations restrict residential developments that encroach on floodplains (for example, through infill, intensification and re-development), subject to some exemptions[ix].
6. Ensure that municipal guidelines require locally-based source controls to counter the impacts of local infill/intensification causing increases in imperviousness in communities over time.
7. Ensure that municipal guidelines require downspout disconnection for all homes from combined and sanitary sewers.
8. Where necessary, define and protect overland flow paths through easements or ownership.
9. Develop and regularly update protocols for collecting accurate flood report data from residents to inform future flood risk investigations and remedial works (e.g. 311 calls).
10. Ensure that procedures are in place that clearly outline responsibilities for flood risk management and stormwater infrastructure operations and maintenance for key stakeholders (homeowners, conservation authorities, municipalities, etc.).
11. Secure adequate resources for stormwater management services, including inspections and maintenance programs. To this end, consider the implementation of dedicated stormwater rates, structured to incent private-side flood risk reduction actions.
12. Ensure that flood forecasting and warning protocols are in place, which include standard messaging and communication protocols.
13. For frequently flooded areas, maintain a stock of emergency flood-protection supplies (e.g., temporary flood barriers and sandbags). Ensure that local community and emergency responders are trained on their deployment.

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ix In some communities, there are designated "special policy areas", whereby development that encroaches within the floodplain can still proceed, subject to flood proofing/protection measures. These measures may include raising building openings, electrical and mechanical systems above the regulatory flood level, installation of backflow valves, and the use of flood damage resistant materials in basements.

4.2 Operations and Maintenance Programs

Riverine Flooding

1. Regularly (e.g., every 5 to 10 years) inspect and maintain watercourse corridors through strategic vegetation management and debris removal.
2. Regularly (e.g., annually) inspect and maintain culverts, bridges and other flood control structures (e.g., dykes and dams).
3. Proactively drain water in designated flood storage systems (e.g., reservoirs, ponds, cisterns, etc.) prior to major forecasted flood events.
4. Where ice jams are common, proactively monitor and manage riverine ice.

Overland Flooding

1. Inspect and maintain critical overland flow paths prior to major forecasted flood events.
2. Remove snow in critical overland flow paths prior to spring thaw.
3. Proactively clear and thaw critical catch basins and culverts prior to spring thaw and major forecasted flood events.
4. Proactively clear fallen leaves from catch basins, culverts and inlets in the fall.

Storm and Sanitary Sewer Back-Up

1. Regularly (e.g., annually) inspect and maintain catch basins, outfalls and inlets.
2. Regularly (e.g., every 5 to 10 years) inspect and maintain storm and sanitary sewers. For problematic areas, develop a frequent cleaning list of storm and sanitary sewers.
3. Where cost-effective (e.g., at the time of neighbourhood re-development), implement roof leader and foundation drain disconnection programs.
4. Identify and remediate areas of significant inflow and infiltration into the sanitary sewers (e.g. through sewer flow monitoring, dye testing, smoke testing, CCTV inspections, etc.).

4.3 Public Engagement

1. Educate residents on private-side flood prevention measures and maintenance activities (e.g., using insights from CSA- Z800-18 basement flood protection and risk reduction guideline).
2. Provide information packages and electronic reminders to residents as related to flood prevention measures and maintenance activities on their property.
3. Engage with home inspectors, realtors, insurance and mortgage brokers to partake in public education programs on flood risk reduction.
4. Implement public art projects to raise awareness of flood risk (e.g., use art to indicate high water levels for riverine and overland flooding).
5. Encourage realtors to disclose past history of floods for properties, as well as current flood risk scores (e.g., as determined through home flood risk assessments performed by trained home inspectors).
6. Market any available subsidies so that residents are better-aware of financial incentives to implement flood-resiliency measures on private properties.

4.4 Selected Physical Interventions to Reduce Flood Risk

Presented below are some physical interventions that municipalities, utilities and relevant authorities can implement to reduce flood risk for existing residential communities in Canada. The list of physical interventions presented herein is not exhaustive, and has been developed based on input from the consulted experts, who contributed to the development of this report.

Prior to implementation of these interventions, flood risk assessments of varying complexities may need to be conducted, including modelling, environmental assessments, cost-benefit analyses, etc. Care should be exercised when selecting interventions for implementation, as addressing one flood risk in isolation may introduce or exacerbate other flood risks. As well, some best practices may only be economically viable at the time of re-development or infrastructure renewal. Depending on the intervention, multiple storm water management objectives (e.g., flood risk reduction, water quality improvement and urban heat island reduction) can be achieved through individual or combined application of the interventions listed below, and should be considered accordingly. Note the capital cost and ease of implementation rankings, which accompany each intervention listed below would be expected to vary depending on local conditions and issues. Further, capital cost rankings are not normalized with consideration of performance effectiveness. Each application should be assessed on its own merits relative to performance objectives.

4.4.1 Riverine Flooding:

Examples of Physical Interventions	Capital Cost	Ease of Implementation
Retrofit existing or construct new flood control infrastructure to reduce peak flows in watercourses	High	Complex
Buy-out (expropriate) residential properties subject to frequent and repeated riverine flooding	High	Complex
Upgrade capacity of water crossings, channels and valley corridors to meet the desired level of service	High	Moderate
Protect properties adjacent to watercourses to meet the desired level of service (e.g., through construction of floodwalls, berms, lot re-grading, structural and electrical improvements)	Med	Complex
Implement flood forecasting and warning systems	Low	Moderate

4.4.2 Overland Flooding:

Examples of Physical Interventions	Capital Cost	Ease of Implementation
Upgrade overland system capacity and operation (e.g., as part of road retrofits and reconstruction, improve channeling of overland flows away from buildings; introduce additional overland outlets; re-grade roadways; retrofit inlet grates to prevent blockages)	High	Complex
Introduce off-line and on-line storage facilities (e.g., storage tanks)	High	Complex
Protect properties located in low-lying areas to meet the desired level of service (e.g., through construction of floodwalls, berms, re-grading, structural and electrical improvements)	Med	Complex
Modify lot grading and increase minimum building elevations during neighbourhood re-development phases	Med	Complex
Retrofit existing stormwater management facilities (e.g., upsize existing ponds)	Med	Moderate

Maintain natural infrastructure (e.g., wetlands and watercourse corridors) and consider low impact development practices to complement grey infrastructure solutions for stormwater management	Med	Moderate
Where reverse-grade driveways exist, consider introducing driveway "humps" to reduce the risk of stormwater runoff entering private property flowing from the street	Low	Simple

Please refer to the CSA Group Guideline on basement flood protection and risk reduction (CSA- Z800-18) for a comprehensive list of practices to reduce the risk of storm and sanitary sewer back-up flooding, as well as measures to reduce foundation system drainage failures. Some example include:

4.4.3 Storm and Sanitary Sewer Back-Up Flooding

Examples of Physical Interventions	Capital Cost	Ease of Implementation
Increase the size of deficient storm and sanitary sewers to allow for additional conveyance capacity	High	Complex
Implement sewer separation projects, with addition of storm trunks to provide additional capacity and relief	High	Complex
Introduce off-line and on-line storage facilities (e.g., storage tanks)	High	Complex
Implement stormwater diversions (e.g., through installing pipes that carry excess stormwater away from overwhelmed areas to areas with more or residual capacity)	Med	Complex
Retrofit existing stormwater management facilities (e.g., upsize existing ponds)	Med	Moderate
Install backwater valves to reduce sewer back-up risk	Low	Moderate
Install inlet control devices (ICDs) to restrict the flow of stormwater from streets into storm sewers	Low	Moderate
Seal and bolt sewer covers in low lying areas[x]	Low	Simple

4.4.4 Foundation Drainage System Failures

Examples of Physical Interventions	Capital Cost	Ease of Implementation
Disconnect direct connections (e.g., roof leaders, foundation drains) to sewers in areas where sewer back-up risk is high	Med	Moderate
Install impermeable layer of soil around homes (i.e. foundation backfill areas) to reduce the risk of water infiltration and seepage through foundation walls	Med	Low
Provide positive grading around foundations to direct water away from foundations walls	Low	Moderate
Install back-up power for sump pumps to prevent failure during power outages	Low	Low
Ensure roof leaders direct water away from home, and into a location with positive drainage	Low	Low
Installing back-up pumps in an event of the primary pump failure	Low	Low

Appendix B contains case studies featuring some physical interventions referenced above, as they have been implemented in Canada.

x Consideration should be given to ventilation requirements to avoid gas build up in the sewers.


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CHAPTER 5: CONCLUSION AND NEXT STEPS

As communities in Canada continue to invest in disaster risk reduction and climate adaptation initiatives, this report provides a framework for prioritizing flood-resilience efforts and outlines approaches to reducing flood risk that are deemed effective by local governments.

The intention is that a future National Standard of Canada will be developed to expand on the foundational framework outlined in this report. Such a guideline would ensure that flood-resiliency initiatives implemented by local governments are selected in a transparent and efficient manner.

To complement this guideline, stakeholders noted that there are a number of key areas requiring further research.

These include:

- Best practice research relating to flood forecasting and warning systems (including determination of an appropriate flood monitoring system density, the pros and cons of using advanced radar systems for flood forecasting, and effective approaches for communicating with the public during flood emergencies);
- Best practice research relating to operations and maintenance (O&M) of stormwater and river management infrastructure, including research on routine inspections and maintenance activities, as well as infrastructure assessments and performance monitoring;
- A review of approaches that would explain how to model the impacts of "rain on snow" events and spring melt events for stormwater management planning; and
- A review of financing approaches for stormwater management and infrastructure retrofits in light of a changing climate.

As Canada moves forward to meet the climate adaptation and disaster risk reduction commitments under the Paris Agreement,[37] the United Nations' Sendai Framework for Disaster Risk Reduction (DRR)[38] and the Pan-Canadian Framework on Clean Growth and Climate Change, the development of the National Standard of Canada for flood-resilience in existing communities warrants significant attention.

DEFINITIONS

Backwater valve: a device that prevents storm or sanitary sewage in an overloaded main sewer line from backing up into a basement. The valve automatically closes, if the flow from storm or sanitary sewage reverses, and attempts to back-up into a basement from the main sewer.

Coastal Flooding: flooding associated with a defined shoreline along an ocean. Can occur due to a combination of high tides, storm surges, waves, rising sea levels.

Combined Sewer: sewer that is designed to carry both wastewater and stormwater.

Design Flood: a flood standard associated with a peak flow used for planning, infrastructure design or floodplain management investigations. It is typically defined by its probability of occurrence, or estimated using a selected design storm.

Design Storm: a temporal rainfall distribution used for the assessment and design of drainage systems, which incorporate statistical rainfall data (intensity, durations and frequencies (IDF)) for a given geographic location.

Dual Drainage: combination of minor system designed for more frequent storms and major system designed to convey runoff for infrequent storms.

Floodplain: an area adjacent to a lake, river or coast, which can be expected to be regularly inundated or covered with water. It typically includes two zones:

- Floodway: the channel of the river or stream and the adjacent land that must remain free from obstruction so that the regulatory flood can be safely conveyed downstream.
- Flood Fringe: the remaining portion of the floodplain, where flood depths, flow velocities, or wave energies are relatively lower and some development may be permitted, if adequate levels of flood protection are provided.

Flood Mechanisms: the condition, which causes a specific type of flood (e.g., blocked culvert leading to overland flooding).

Flood Mitigation: a sustained action taken to reduce or eliminate long-term risk to people and property from flood hazards and their effects. Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from specific events.

Flood Risk: flood risk is a combination of the likelihood of occurrence of a flood event and the social or economic consequences of that event when it occurs.

Flood Risk Map: maps that contain the flood hazard or inundation delineations along with additional socio-economic values, such as potential loss or property vulnerability levels. These maps serve to identify the social, economic and environmental consequences to communities during a potential flood event.

Floodproofing: any combination of structural or non-structural measures that reduce or prevent flood damage to the structure and/or its contents.

Flood Protection: any combination of structural and non-structural improvements, additions, changes, or adjustments to structures, which reduce or eliminate risk of flood damage to real estate or improved real property, water and sanitation facilities, or structures with their contents.

Groundwater Seepage: groundwater that enters through weeping tiles, sump pits, crawl spaces, cracks, pores or gaps in foundation walls, cracked pipes or other openings.

Impervious surfaces: surfaces that resist the absorption of water into the ground (e.g., paved surfaces such as roads and parking lots, as well as buildings, driveways and hardscaping).

Infiltration (Sewer): extraneous water entering a sewer system (sanitary or storm), including building sewers (laterals), from the ground through defective pipes, pipe joints, connections or manhole walls.

Inflow (Sewer): extraneous water directly discharged into a sanitary sewer system, including service connections, from roof leaders; cellar, yard or area drains; foundation drains; drainage from springs and swampy areas; manhole covers; interconnections from storm sewers; combined sewers and catch basins; storm waters; surface runoff; street wash waters or drainage.

Infill: development within urban boundaries not related to large-scale development plans, but rather smaller scale development in remnant vacant parcels.

Inlet Control Device (ICD): a device typically fitted inside catch basins to reduce the rate of flow into storm sewers.

Intensification: land use planning phenomenon whereby existing urban lands are transformed into higher densities (people and coverage).

Intensity-Duration-Frequency (IDF) curve: a graphical representation of the probability that a given depth of rainfall will occur, shown in rainfall intensity (e.g., in millimeters per hour) with respect to rainfall duration (e.g., hour).

Lateral: any pipe from a building connected to the main sewer.

Lake Flooding: flooding associated with defined land area along a lake. Can occur due to a combination of high water levels, waves, and storm surges.

Minor Drainage System: storm sewers, catch basins, inlets, inlet control devices, street and roadway gutters, ditches and swales designed to convey runoff from frequent storms.

Major Drainage System: streets, trunk sewers, channels, ponds, ditches, swales, natural streams and valleys that accommodate runoff, including excess runoff from storms over and beyond the minor drainage system capacity.

Overland Flooding: flooding that occurs when runoff exceeds the hydraulic capacity of the storm sewers, ditches and catch basins, causing excess water to flow on the streets and then onto, between, and across residential properties. It can happen anywhere in the community.

Peak Flow: the maximum flow rate occurring during a specified flood event measured at a given point in a river, overland, or in a pipe system.

Re-development: conversion of existing urban uses of lower value and significance to other preferred uses per a community plan (e.g. brownfield redevelopment to residential uses).

Regulatory Flood: the defined flood event used to delineate areas prone to flooding for the purposes of regulating land use. The minimum regulatory flood criteria standard in Canada is the 100-year return period flood, which is the peak flood flow with a one percent chance of occurring in any given year. Some regions, provinces, and territories implement standards that are more stringent.

Riverine Flooding: excess stream flow in a watercourse, such that land outside the normal banks is submerged or inundated. Riverine flooding can be caused or exacerbated by extreme rainfall, snowmelt, physical conditions (e.g., ice, sediment and debris jams, watercourse configuration and capacity limitations), as well as elevated water levels in receiving waterbodies.

Roof leader: a drainpipe that conveys storm water from the roof of a structure to a sewer for disposal onto the ground and removal from the property (also referred to a downspouts).

Runoff: the amount of water deriving from precipitation/snowmelt, not otherwise evapotranspirated or stored, that flows across the landscape.

Sanitary Lateral: An underground sewer pipe that connects a private sanitary drainage system to a public sanitary sewer main. This type of service is designed to collect sanitary sewage; however, in older systems it may also convey storm water.

Sanitary Sewer: part of the public sewage works for the transmission of sanitary sewage (includes human and industrial waste, and septic waste, but not typically stormwater).

Sewer Back-Up (Surcharge): a condition when the sewer flow exceeds the hydraulic capacity of the sewer, causing back-up.

- Storm sewer back-up occurs when storm sewers are overloaded by stormwater runoff causing surcharge and back-up into homes through storm sewer laterals connected to the foundation drain system. Storm sewers can also back-up to surface, contributing to overland flooding.
- Sanitary sewer back-up occurs when sanitary sewers are overloaded through inflow and infiltration preventing sanitary effluent to be properly conveyed away from home to the sanitary sewer.
- Combined sewer back-up occurs when combined sewer systems (legacy design whereby storm and sanitary were conveyed in a common pipe) are overloaded by stormwater runoff preventing sanitary effluent tobe properly conveyed away from home to the combined sewer.

Source Control: techniques used to reduce the volume, rate and improve quality of stormwater runoff by managing rainfall close to where it falls.

Standardization: the development and application of standards that establish accepted practices, technical requirements, and terminologies for products, services, and systems.

Stormwater: precipitation that washes off driveways, parking lots, roads, yards, rooftops, and other surfaces.

Stormwater Management: the planning, design and implementation of systems that mitigate and control the impacts of man-made changes to runoff and other components of the hydrologic cycle. Stormwater management is also referred to as "rainwater management" in much of the world.

Storm Lateral: An underground sewer that connects a private storm and/or foundation drainage system to a public storm sewer main.

Storm Sewer: a sewer, the purpose of which is to carry stormwater (including surface and rainwater, melted snow and ice) and water in underground pipes and foundation drains.

Sub-catchment: a physical demarcation of a land area, which contributes runoff to a common point. Watersheds and sub watersheds are comprised of many sub-catchments. In urban settings, sub-catchments typically drain to an outlet (e.g. a watercourse or lake).

Sump pump: A mechanical device located in sump pits (depression proximate to the foundation, which collects the foundation water), used to pump foundation drainage discharge and/or groundwater to the surface of the lot or to a sewer lateral.

Swale: A sloped, shallow channel used to convey stormwater toward appropriate stormwater management

Third pipe system: An underground stormwater or foundation drainage collection system. Third pipe systems are typically designed to convey foundation drainage, roof drainage or a combination of foundation and roof drainage via a "third pipe" under the public street (i.e., after the sanitary and storm pipe).
A Foundation Drain Collector (FDC) system is an example of a third pipe system.

Wastewater (Sanitary Sewage): A mixture of blackwater (used water from sanitary appliances that contains human fecal matter or human urine), greywater (used water, other than blackwater, from sanitary appliances or from other appliances in a kitchen or laundry), and discharges from industrial, commercial and institutional facilities.

APPENDIX A: HISTORICAL REVIEW OF NATIONAL BUILDING CODE CHANGES THAT IMPACT THE FLOOD-RESILIENCE OF RESIDENTIAL DWELLINGS

Prepared by: Michel Frojmovic, Director, Acacia Consulting
Prepared for: Intact Centre on Climate Adaptation and Canadian Home Builders' Association

Acacia Consulting conducted a review of Canada's National Building Codes (NBC) from 1941 to 2015 to identify key flood-resiliency updates introduced to the code over time. The review pertained to code provisions that focus on measures on the private-side of the property line to address storm and sanitary sewer back-up risk, overland flooding and groundwater seepage.

Access to the digital copies of the NBC were provided to Acacia Consulting by the National Research Council of Canada (NRC). Where applicable, the National Plumbing Code (NPC) provisions were reviewed as well.

Table 9 summarizes key findings from the review. The column Edition & Section identifies the year of the code edition and the corresponding section. The column Code Provisions either summarizes or recites the provision for concision.

*Table 9: Summary of flood-resiliency updates to Canada's National Building Code (NBCO and National Plumbing Code (NPC), 1941-1995**

Edition & Section	Code Provisions
Property Grading	
NBC 1941 K1.2.9 House drain	…receives the discharge from soil, waste, or other drainage pipes and conveys it to a point, not less than three feet beyond the wall of the building, there discharging it to a house sewer.
NBC 1953 Part 7 Plumbing Services	Building drains direct discharge to the building sewer beginning 3 feet outside the building.
NBC 1960 Part 7 Plumbing Services	Building sewer means a pipe that is connected to a building drain 3 ft. outside of a wall of a building to conduct sewage, clear water waste or storm water to a public sewer or private sewage disposal system.
NBC 1970 9.14.6.2	The building site shall be graded to direct surface water away from the building.
NBC 1975 9.14.6.1	The building shall be located or the building site graded so that water will not accumulate at or near the building.
Backfill	
NBC 1941 5.6.2 Damp-proofing of Basements	Basements shall be constructed on porous backfill with relatively impermeable soil backfilling the walls.
NBC 1980 4.2.5.8(2)	Backfill material must be of a type not subject to detrimental volume change in moisture control and temperature.
NBC 1980 9.12.3.2	Backfill shall be graded to prevent drainage towards the foundation after settling.
NBC 1990 9.12.3	Backfill must be able to support footing and foundation.
Downspouts and Sewer Connections	
NBC 1953 7.10.3 Separate Systems	The sanitary and the storm drainage systems of a building shall be entirely separate except where only a combined sewer is available.
NBC 1970 7.4.4.1	Every fixture shall be connected to a sanitary drainage system.
NBC 1970 9.27.15 Down-spouts and roof drains	Where downspouts are provided and are not connected to a sewer, extensions shall be provided to carry rainwater away from the building in a manner which will prevent soil erosion.

Drain Pipe	
NBC 1970 9.14.5	Drainpipe or tile shall drain to a sewer, drainage ditch, or dry well. Where gravity drainage is not practical, a covered sump with an automatic pump shall be provided to discharge the water into a sewer, drainage ditch or dry well.
Backwater Valves	
NBC 1941 K4.3.9 Back-water Valves	Backwater valves shall have all bearing parts of corrosion-resisting metal and shall be so designed and constructed as to assure a positive seal against backpressure but permit the free flow of waste.
NBC 1960 7.5.2.2(3)	Where an overflow from a rainwater tank is connected to a sanitary drainage system a backwater valve shall be installed on the overflow pipe.
NBC 1960 7.5.9.5(1)	Where a building drain is subject to backflow a gate valve or a backwater valve shall be installed on the fixture drain of a fixture.
NBC 1970 7.4.2.2(3)	Where an overflow from a rainwater tank is connected to a sanitary drainage system a backwater valve shall be installed on the overflow pipe.
NPC 1975 4.6.4(1)	A backwater valve or a gate valve shall not be installed in a building drain or in a building unless approved.
NPC 1995 4.2.1	A backwater valve shall be installed in a storm drainage system that is subject to backflow.
Sump Pumps	
NBC 1941 K5.5.8.11 Sumps and Receiving Tanks	All sub-house drains shall discharge into an airtight sump or receiving tank, so located as to receive the sewage by gravity, from which the sewage shall be lifted and discharged into the house sewer by pumps, ejectors, or other equally efficient method, operated automatically. When sub-house drains do not receive the discharge from plumbing fixtures other than cellar floor drains the sump or receiving tank need not be airtight or vented.
NBC 1953 7.5.8 Drainage below Sewer Level	All building subsoil drains carrying sewage or similar wastes shall discharge into a leak-proof sump or receiving tank, so located as to receive the sewage by gravity. The sewage shall be lifted and discharged into the building sewer by a pump, an ejector, or other equally efficient method.
NBC 1960 7.5.9.4(1)	Piping that is too low to drain into a building sewer by gravity shall be drained to a sump or receiving tank.
NBC 1970 9.14.5.2	Where gravity drainage is not practical, a covered sump with an automatic pump shall be provided to discharge the water into a sewer, drainage ditch or dry well.
Joints and Connections	
NBC 1941 K5.2.1	All joints and connections shall be made gas and watertight.
NBC 1953 7.6.1	All joints and connections used in a plumbing system shall be airtight and watertight and shall be capable of meeting tests.
Weeping Tiles	
NBC 1941 K6 Inspection and Testing	Every part of the drainage system shall be tested by means of a water test.
NBC 1953 7.3.1 Quality of Material	Material used in any part of a plumbing system shall be free from defects, which may affect its usefulness for purposes of sanitation.

** No substantive changes regarding flood-resiliency provision were made to NBC and NPC between 1995-2015*

APPENDIX B: SELECT PHYSICAL INTERVENTIONS IMPLEMENTED TO REDUCE FLOOD RISK IN EXISTING RESIDENTIAL COMMUNITIES, CANADA

Davis Creek Flood Control System, City of Hamilton, Ontario

Twin cell culvert system, Davis Creek, City of Hamilton, Ontario. Left cell is to be fitted with an automated flood gate; right cell is fitted with a back-up manual gate.

Location: City of Hamilton, Ontario

Construction dates: 2012 - 2015

Implemented on public property: Public property - King Street, Red Hill Valley Parkway, Southeast Ramp, City of Hamilton, Ontario

Engineering Team: Ron Scheckenberger, Project Manager and Aaron Brouwers, Project Engineer (Amec Foster Wheeler)

Related Best Practices: Introduction of on-line storage facilities / Construction of new flood control infrastructure to provide over-control and reduce peak flows in flood vulnerable areas

Description: The $400 million Red Hill Valley Parkway in the City of Hamilton is built in the bottom of a valley and as such is at risk from riverine flooding. In order to address flood risk and improve the overall safety of the Parkway for motorists, Amec Foster Wheeler developed an innovative flood control system on the largest tributary to the Red Hill Creek. The Davis Creek flood control system uses over 350,000 m^3 of natural valley storage (online) upstream of the Parkway. A twin cell box culvert conveying Davis Creek through a highway ramp structure was originally proposed to be partially blocked to temporarily hold back flood waters, much like a conventional on-line dry stormwater detention facility. However, such simple blockage of the culverts would introduce the risk of overtopping if not properly managed. Therefore, Amec Foster Wheeler designed an automated gate system whereby the gates remain open until the watershed experiences a large flood (a 25 year storm or greater), at which point it would close, effectively backing up water in the natural Davis Creek valley. Should the flood continue to approach critical levels, the gate would slowly open, avoiding an overtopping condition.

Drainage area: 12.5 km^2 (about 20% of the whole of the Red Hill Valley, which is about 63 km^2).

Cost:

- Planning and design: CAD $100,000
- Construction: $1,800,000
- Annual O&M costs: to be confirmed, the O&M manual is under development.

Performance results: The automated gate system reduces flood peaks downstream in the Red Hill Creek by 15% for a 100 year event which is the design standard used for the expressway. This improves the highway safety and substantially reduced overall infrastructure costs related to lower roadway platform elevations (resulting in less fill), smaller bridge crossings and associated channel geometry. A back-up power system (generator) ensures that the gate system is operational in the event of a power outage and a manual override, in the event of total system failure or an overtopping flood can open up the gate. In addition, the system is capable of communicating status of its operations (closed or open) to operations and maintenance staff at the City of Hamilton, in order to inform them of flood stage in case human intervention is required to operate the gates.

Non-flood related benefits from project implementation:

- Biodiversity benefits: small and medium wildlife (e.g., deer and other small mammals) can move through the valley; similarly, fisheries access is unencumbered by any man-made barriers as the culvert system is open the majority of the time.

Pelly's Lake Wetland Restoration Project, Manitoba

Restored wetland in Pelly's Lake, Manitoba.

Location: Pelly's Lake, Holland, Manitoba

Construction dates: 2014-2015

Implemented on public property: The area straddles the property of seven landowners, which the LaSalle Redboine Conservation District manages under an easement agreement.

Engineering Design Team: Ken Rakhra, Province of Manitoba and the LaSalle Redboine Conservation District staff.

Related Best Practice: Using natural infrastructure solutions (e.g., wetlands and ponds) to complement grey infrastructure solutions for stormwater management.

Description: The 121-hectare Pelly's Lake water retention area is located on a heavily-drained agricultural land upstream of a high-flood-risk area of the Boyne River, a tributary of the Red River. The Red River has a history of severe flooding and contributes approximately 60% of the nutrient load to Lake Winnipeg, the most eutrophic large lake in the world.

In 2015, a retention structure was built to manage water releases at Pelly's Lake, effectively transforming a natural slough and marginal agricultural land into an engineered wetland and reservoir. The key benefits of the engineered wetland include the ability to control water releases for flood attenuation and late-season recharge of waterways further downstream (a drought mitigation benefit).

Cost:

- Planning and design: $10,000 (including engineering time, soil samples and consultant fees)
- Capital cost: $1,017,183
- Annual O&M cost, including harvesting of cattail: $125,000

Performance monitoring results: In 2017, University of Saskatchewan researchers assessed the net economic benefits of Pelly's Lake project at $3,700,148 CAD, assuming a 20-year life cycle and 3% discount rate. This assessment reflected the value of flood attenuation, nutrient load reduction (phosphorus and nitrogen) and carbon dioxide offset benefits.

Non-flood related benefits from project implementation:

- Biodiversity benefits: the project increased the diversity of plant and bird species (e.g., the University of Saskatchewan researchers observed increase in waterfowl and songbirds species).
- Water quality improvements: reduction in nutrient load to Lake Winnipeg (phosphorus and nitrogen) through cattail harvesting. Cattail, which flourishes in the wetland area, consumes large amounts of nitrogen and phosphorus, which helps reduce the nutrient load.

Flooding Investigation in Orleans, City of Ottawa, Ontario

Storm sewer surcharging on St. Joseph Boulevard in Orleans, City of Ottawa (2006).

Location: City of Ottawa, Ontario

Construction dates: 2009 - 2010

Implemented on public property: The study area consisted of seven residential sewersheds in the Orleans community in City of Ottawa, with a total area of approximately 1,400 ha.

Engineering Team: Four of the seven basins were studied internally by the City of Ottawa Staff. The remaining three basins were studied by Stantec Consulting, Delcan (now Parsons) Engineering and Jean Francois Sabourin and Associates.

Related Best Practices: Detailed dual drainage analysis to optimize the existing storm system / Installation of inlet control devices (ICDs) throughout all basins to minimize sewer surcharge / Major system improvements to maximize storage and improve conveyance / Installation of new storm sewers to provide relief at critical low points / Replacement of storm sewer manhole covers.

Description: On July 3rd, 2006, part of the Orleans community in Ottawa was hit with a storm that was greater than the 100-year return frequency rainfall event. Subsequently, on August 2nd, 2006, the area was hit with another significant rainfall event. During both of these storms, significant ponding occurred on some City arterial roadways and on private property, but the vast majority of flooding reports were due to water entering basements via the city sewer system. Over 800 homes reported basement flooding. As a result, the City of Ottawa undertook a detailed dual drainage analysis of the affected area to find alternative solutions that would provide basement protection, similar to today's standards. The solution consisting of the following:

- Installation of ICDs in all catch basins.
- Replacement of all storm manhole covers with solid covers to eliminate ICD by-pass.
- Re-grading of pathways and street sections to direct flow away from homes and towards major system outlets.
- Re-grading the entrance of depress driveways to stop excess street runoff from spilling into these driveways.
- Constructing high-level storm sewers to drain low points in critical arterial roadways that suffered excessive ponding depth and were therefore a significant safety hazard.
- Upgrading storm sewers that were acting as "bottlenecks" in the system.

Drainage area: 1,400 ha

Cost:

- Planning and design: CAD $675,000
- Construction: $4,325,000
- Annual O&M costs: work undertaken as part of regular infrastructure O&M.

Performance results: In 2011, the Orleans community suffered another large event that closely resembled the 2006 storm events. There were no reports of basement flooding in the seven basins where flood remediation work was implemented. Complaints related to excessive ponding on residential streets, encroachment of ponding onto private properties and erosion of landscaping and gardens due to major system flow relief. Following the 2011 event further tweaking of the system was done to minimize future impact to private property; however in most cases City staff simply informed the public about the benefits of keeping the water on the surface ("Better on the street than in your basement").

Flood Alleviation Program (FLAP), City of St. Catharines, Ontario

Location: St. Catharines, Ontario

Implementation dates: annual program (1995 – present)

Implemented on public or private property: Private property

Type of intervention: The St. Catharines Flood Alleviation Program (FLAP) offers grants of up to $3,500 to eligible residents to help cover the costs of installing flood protection devices such as backwater valves, sump pump and weeping tile disconnection on private property.

Related Best Practices: Downspout disconnection from sanitary and combined sewers / Foundation drain disconnection programs to reduce potential for inflow into the sanitary sewer system / Public engagement.

Description: The objective of the FLAP program is to provide immediate basement flooding protection for homeowners, while long term solutions are investigated and implemented. It is specifically intended to protect houses that have been flooded due to main sewer surcharging during heavy rainfalls.

The program provides a grant to homeowners with documented basement flooding problems related to sewer surcharges. Once a homeowner applies to the program, the application is reviewed. A team of staff then visits the property to determine the cause of flooding, identify a solution and approve a scope of work. Typically the scope of work includes a backflow prevention device installed on the building's main sewer lateral, the disconnection of foundation drains from the sanitary sewer and reconnection to a sump for discharge to the surface, as well as basic restoration works.

Homeowners are required to obtain competitive quotes for the eligible works from plumbing contractors. The City does not recommend or pre-qualify any of the contractors. The amount of the grant is determined by the lowest quote. In a typical FLAP installation, the homeowner does not incur any out-of-pocket costs.

The homeowner then arranges for a plumbing contractor to obtain a plumbing permit and perform the work. Once the work is complete and has passed the plumbing inspection the grant is released to the homeowner, who in turn will pay the contractor. All warrantee issues are the responsibility of the contractor.

Once installed, minor maintenance work is required by the homeowner to ensure the backwater valve continues to operate properly on a semi-annual basis.

Drainage area: This is a city-wide program.

Cost:

- The annual budget for FLAP grants is currently $100,000. However the number of homeowners applying for the program varies significantly from year to year and depends heavily on the number of extreme rainfall events. In years where the demand exceeds the budgeted amount, additional funds are via in-year budget amendments. Residents have never been turned away due to lack of budget funding.
- Since the program's inception in 1995, over 1.6 million dollars of FLAP Grants have been provided to approximately 700 properties.
- In addition to the grant cost there are additional staff costs operate the program. The program covers the costs of a plumbing permit ($220 per property) and a CCTV inspection of the sanitary lateral ($200 per property).

Annual O&M costs: There are no significant annual O&M costs incurred by the City for this program. The homeowner is responsible for maintaining the devices and any utility costs (e.g. electricity for the sump pump).

Performance monitoring results: The mainline backwater valves are reliable, but subject to failure if the homeowner does not perform routine maintenance. This has occurred, especially in instances where home ownership has changed and the new homeowner may not be aware of the device and maintenance requirements.

St. Catharines has also installed monitors on the sump pumps to measure the amount of weeping tile flows which are being taken out of the sanitary sewers. Based on these flow measurements it is estimated that 110 cubic metres of flow is diverted from the sanitary sewer for each weeping tile disconnection annually.

Non-flood related benefits from project implementation:

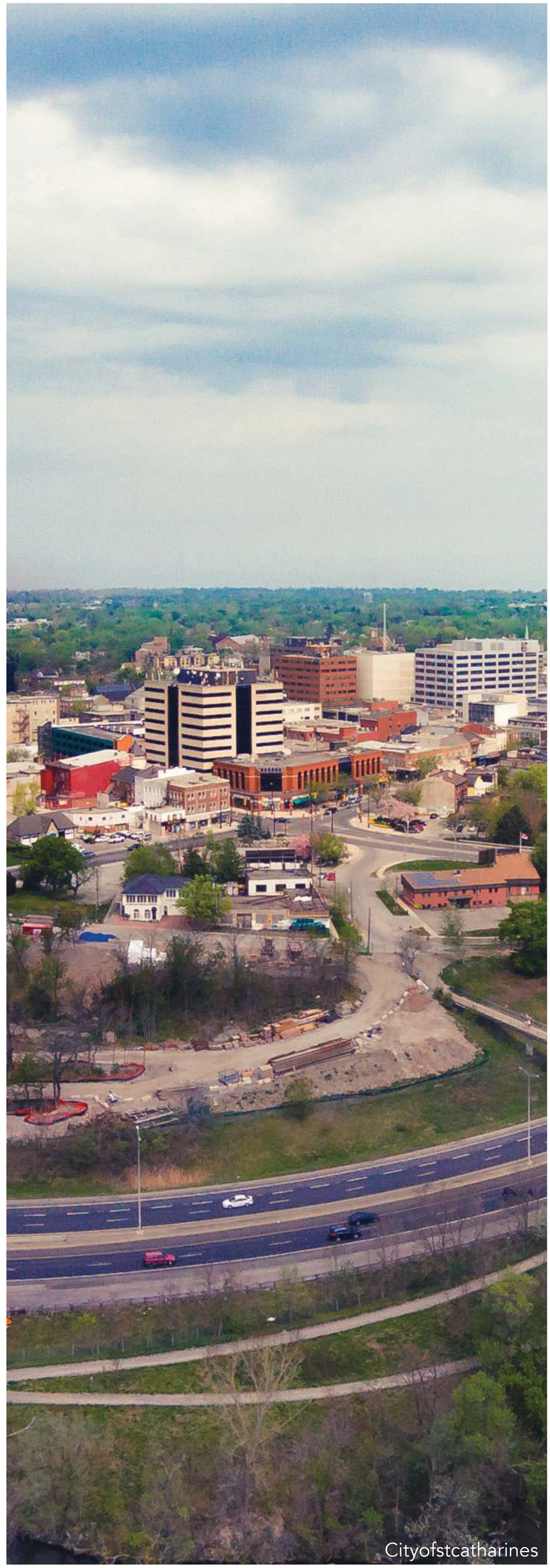
There are several additional benefits to the program. First, the program encourages residents to notify the city about flooding issues. When the city staff investigate these issues, they may find other problems on public and private side that increase flood risk. For example, they may find that there are partial blockages of the main sanitary sewer, deteriorating conditions of the lateral, cross connections and illegal sump pumps configurations (e.g. sump pumps discharging into the sanitary sewer), as well as other issues that would have otherwise remained unobserved and unaddressed.

The program provides an opportunity to educate residents about plumbing and wastewater collection system issues and actions they can take to protect themselves from flooding. This can help some homeowners to obtain or maintain basement flooding insurance coverage.

Lessons learned / public feedback: The FLAP program has been successful, with over seven hundred properties benefitting from the City's assistance. The number of applications in any given year depends on the number of extreme rain events. While FLAP is not a solution to all types of flooding, it can be an effective short-term solution to sewer back-up.

There has been strong support for this program from City Council, as it is seen as a direct and immediate action to assist homeowners in flood risk reduction. In comparison, infrastructure upgrades may take several years to be completed.

As a general point, residents who have not been flooded are not interested in the program. The work can be disruptive (e.g. breaking up a concrete basement floor to install a backwater valve or sump pit). However, residents who have been flooded are often motivated to participate in the program.


Cityofstcatharines

Combined Sewer Separation Project, City of Charlottetown, Prince Edward Island

Location: Charlottetown, PEI

Construction dates: 2004 – 2006 and 2012 - 2016

Implemented on public property: Brighton and Spring Park neighborhoods

Engineering Team: Pat Hughes, Project Manager (CBCL Ltd.) and Luc Van Hul, Project Manager (WSP Engineer Ltd.)

Related Best Practices: Constructing separate sewer system to reduce sanitary sewer bypasses and provide additional capacity and relief.

Description: Prior to the separation project, the combined sewer line in two Charlottetown neighborhoods would collect sewage from residential, commercial and industrial properties as well as storm water and direct the flow to the city's wastewater treatment plant. During heavy rainfall events or the spring snowmelt, the precipitation would mix with untreated effluent, and at times exceed the capacity of the treatment plant and excess water that contained untreated sewage would flow into the Hillsborough Harbour.

In 2004, the City of Charlottetown Water and Sewer Utility authorized CBCL to provide preliminary design, site inspection and contract administration services for the construction of 6.3 km of new sanitary gravity sewer and forcemain in the Brighton area of Charlottetown.

The project involved installation of a new dedicated sanitary sewer system in an area currently serviced with a combined sewer system. New sanitary services were installed to each property and connected at the right-of-way. A lift station was installed to pump flows from the new, deeper sanitary system. The project features included:

- 905 m of 300 mm dia. sewermain
- 4,320 m of 200 mm dia. sewermain
- 850 m of 200 mm dia. sewermain
- 3,300 m of 100 mm dia. sewer service laterals
- 220 m of 150 mm dia. forcemain
- Approximately 341 service laterals
- 105 manholes
- Pump sewer shed – size 159 acres (64.4 hectares)
- A 7.5 hp sewage duplex pump lift station, equipped with a manual transfer switch for emergency power supply in event of electrical supply failure.

Following commissioning of the Colonel Gray Drive sewage pumping station and the gravity sewer, the existing combined sewer started functioning as a dedicated storm sewer. Separated flows from the Brighton area were then pumped at the Brighton lift station into the City's existing 60-inch combined trunk sewer located in the Spring Park sewershed until the next phase of the project.

Following the completion of upgrades at the Charlottetown Pollution Control Plant to secondary treatment, and completion of the separation of combined sewer in the Brighton area of Charlottetown, and as a continued effort to resolve the operational and environmental issues associated with combined sewer overflows, the City of Charlottetown retained WSP to proceed with a project to separate the remaining combined sewer system within the Spring Park area.

The project generally includes the design and installation of new sanitary sewer mains, services, manholes, lift stations, forcemains and reinstatements throughout the combined sewer area. The project also included trenchless technologies such as CIPP rehabilitation of a sewer main and directional drilling in the areas with limited space and/or no easement. The design was primarily based on the requirements of the Atlantic Canada Wastewater Guidelines Manual for Collection, Treatment and Disposal, and the new sanitary sewer system is expected to have a service life of 100 years or more. Design of the new system accounted for the ultimate potential serviced population (in this case 100+ years) within the tributary sewersheds. WSP performed sewer system design, detailed design of two new submersible pumping stations, and detailed design of a wet well/dry well pumping station upgrade.

The project was phased over 5 years of construction with several tenders issued to ensure a timely design and construction. All work, including the consulting and construction, was carried out while the existing mains and services were in operation. Due to the proximity to high traffic areas, this project required the development and implementation of a traffic control plan.

Cost:

- Brighton Section: $4,200,000
- Spring Park Section : $18,000,000

Performance results: Prior to the separation of the sanitary flows from the combined system there were roughly 50 precipitation related events in a year where untreated sewage would be discharged into the receiving waters. Following the separation project there are fewer than five events per year that exceed the treatment plants capacity. The next steps for improvement include additional inflow and infiltration reductions in the other dedicated sanitary sewer collection networks.

Non-flood related benefits from project implementation: Improved water quality in the Hillsborough Harbor and shellfishing, which is managed successfully under the conditional management plan in the harbor.

Scotia Street Secondary Dike Installation Project, City of Winnipeg, Manitoba

Location: City of Winnipeg, Manitoba

Construction dates: 2004-2010 (constructed in phases)

Engineering Team: UMA/AECOM

Related Best Practice: Flood-proof properties adjacent to watercourses to meet the desired level of service.

Description: During the spring of 1997, Manitoba experienced the "Flood of the Century" (i.e., approximately a 1:100 year event) against which the City of Winnipeg successfully protected itself. However, in that effort the city did have to provide materials and equipment for the emergency construction of secondary dikes around some 800 properties, of which 750 properties were provided a total of 8 million sandbags. Following the 1997 flood, a study was undertaken to assess the feasibility of constructing permanent secondary ring-dikes to provide enhanced protection to groups of at-risk homes. One of the key factors used for determining priorities was the benefit-cost ratio, considering potential future emergency flood-protection costs.

The Scotia St. was one of the areas identified as being a high priority, with a favourable return on investment, considering future anticipated costs. The Scotia St. Secondary Dike project provides improved flood protection to over 25 homes located on the river-side of the Primary Line of Defense (i.e., the street) over approximately 470 m length of the Red River. The dike generally runs parallel to the river along the rear-yards of detached single family dwellings. The project was completed in a number of phases as details and agreements were worked out with impacted property owners. The alignment of the new dike is protect from encroachment by a continuous easement area and is also covered by the City's Secondary Dike By-law. The overall Scotia St. Secondary Dike corridor is over 1km long and encompasses works constructed prior to this project, and other properties that did not require supplemental protection.

While the clay-core dike heights exceeded 1.5 m at some locations, the dike crest is below FPL because homeowners were not willing to accept greater impacts to the landscaping of their properties. Furthermore, additional surcharge loads to the riverbank would have necessitated riverbank stabilization works that would have driven down the down the benefit/cost ratio to the point that it may not have been economically rationalized. Nonetheless, the project has realized very significant benefits to the property owners and the City by:

- Providing a continuous, consistent and engineered dike protecting high-risk properties;
- Reducing the frequency that supplemental flood-protection is required;
- Significantly reducing the number of sandbags required;
- Providing a flat unimpeded surface on which to place supplemental flood-protection; and
- Protecting the alignment from encroachments by way of established easements and specific By-laws.

The City of Winnipeg's Secondary Dyke By-law 7600/2000 designates Secondary Dyke Corridors, and regulates construction within Secondary Dyke Corridors. This bylaw also ensures that the City has access to inspect and maintain the corridor. Ultimately because any one segment of the dike protects all others along the dike, the by-law serves to protect interests of the group as a whole.

Funding:

- Secondary Diking Enhancement Program, established after the 1997 flood, with cost-sharing arrangement of 45% Federal, 45% Provincial, and 10% City.

Cost:

- Construction: approximately $415,000 (2004-2010)
- Annual O&M costs: No budgeted annual maintenance. Dike is maintained by private property owners.

Performance results: Since completion of the project, supplemental flood-protection (i.e., sandbags) have not been required in this protected area, while sandbags were required in both 2009 and 2011 at other nearby properties that were not included in the program. The estimated cost of providing sandbags to this area in 1997 was approximately $1M.

Scotia St. Secondary Dikes.

Downtown Flood Mitigation Project, City of Calgary, Alberta

Location: Calgary, Alberta

Construction dates: 2017-2021

Implemented on public property: The river flood mitigation infrastructure is located along the south side of the Bow River, between Peace Bridge and Reconciliation Bridge in downtown Calgary. This initiative comprises of three projects. 1) West Eau Claire Park, 2) Centre Street Bridge Lower Deck Flood Barrier, and 3) Eau Claire Promenade.

Engineering Contact: Andrew Forsyth, River Engineering section, The City of Calgary

Related Best Practice: Construction of a new 1:200 year river flood mitigation barrier to reduce damage from peak river flows in downtown Calgary along the Bow River.

Description: The City of Calgary takes a holistic approach to flood mitigation, relying on multiple lines of defense to build flood-resiliency at the watershed, community and property level. During the 2013 flood, the downtown core was overwhelmed, power was lost, and businesses could not be accessed for at least six days. Downtown is home to 124 head offices, more than 9,000 residents and 150,000 jobs, so increased flood protection in this area is critical.

River flood mitigation in this area includes the West Eau Claire Park (complete Fall 2018) and Eau Claire Promenade barriers which are connected to the Centre Street Bridge Lower Deck Flood Barrier. This infrastructure is seamlessly incorporated into the downtown riverfront public realm space by including earthfill sections of flood protection into the pathway system and by shrouding the concrete flood barrier wall with aesthetically pleasing benches, as well as incorporating a short section of the wall into a planted flower garden area.

The Eau Claire Promenade barrier will also be a combination of earthen berm and concrete flood wall along the existing river public pathway system. This barrier ties to the flood protection provided by the West Eau Claire Park barrier. The barrier system also benefits from the removable flood barriers that are part of Centre Street Lower Deck Flood Barrier. The barriers have an average height of approximately 1 m above the existing pathway. This is high enough to contain the design river flow rate and provide a height allowance of 0.5 m (i.e. freeboard) as a safety factor and to account for debris, wave action, gravel deposition and climate change.

These flood protection measures result in reduced business and economic interruption, as well as increased resilience for critical services and public infrastructure. The Government of Alberta provided funding through the Alberta Community Resilience Program to complete these projects.

Drainage area: This project will protect 80 hectares of Calgary's downtown core to the 1:200 year flood level.

Construction costs: Eau Claire Promenade barrier: $25.6M (design underway), West Eau Claire Park barrier: $3.2M and Centre Street Bridge Barrier: $1.7M (complete 2018).

Performance results: Once complete, the project will connect existing flood barriers at West Eau Claire and Centre Street Bridge as a single piece of infrastructure and mitigate up to a 1:200 year flood event, in combination with operations of existing upstream reservoirs. With construction of a future (conceptual) reservoir upstream of Calgary on the Bow River, flood protection for Calgary's downtown could be increased to an estimated 1:1000 year flood event.

Non-flood related benefits from project implementation: Improved public space adjacent to the Bow River, as flood protection works harmoniously with the Eau Claire Park and Promenade design and is integrated into public spaces.

Figure 1 - Concrete section of West Eau Claire Flood Barrier showing aluminum guides where stop-logs are placed during a flood emergency

Figure 2 - Earthen berm portion of West Eau Claire Flood Barrier

Figure 3 - Earthen berm portion of West Eau Claire Flood Barrier integrated with cycle path and pedestrian promenade

ENDNOTES

1 Government of Canada. 2016. Canada's Way Forward on Climate Change: The Paris Agreement. Accessed at: www.climatechange.gc.ca/default.asp?lang=En&n=24700154-1

2 Government of Canada. 2017. Sendai Framework for Disaster Risk Reduction (DRR) 2015–2030. Accessed at: www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/pltfrm-dsstr-rsk-rdctn/snd-frmwrk-en.aspx

3 Office of the Auditor General of Canada. 2017. Report 2—Adapting to the Impacts of Climate Change. Accessed at: www.oag-bvg.gc.ca/internet/English/parl_cesd_201710_02_e_42490.html

4 Intergovernmental Panel on Climate Change. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Accessed at: www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf

5 Intergovernmental Panel on Climate Change. 2013. Working Group I Contribution to the IPCC Fifth Assessment Report. Climate Change 2013: The Physical Science Basis. Accessed at: www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_Chapter14.pdf

6 Environment and Climate Change Canada, 2017. Climate Data and Scenarios for Canada: Synthesis of Recent Observation and Modelling Results. Chapter 3.3. Extremes. Accessed at: www.canada.ca/en/environment-climate-change/services/climate-change/publications/data-scenarios-synthesis-recent-observation/chapter-3-3.html

7 Fraser Basin Council. 2016. Lower Mainland Flood Management Strategy. Phase 1 Summary Report. Accessed at: www.fraserbasin.bc.ca/_Library/Water_Flood_Strategy/FBC_LMFMS_Phase_1_Report_Web_May_2016.pdf

8 Public Safety Canada. 2016–2017 Evaluation of the Disaster Financial Assistance Arrangements. Accessed at: www.publicsafety.gc.ca/cnt/rsrcs/pblctns/vltn-dsstr-fnncl-ssstnc-2016-17/vltn-dsstr-fnncl-ssstnc-2016-17-en.pdf

9 Office of the Auditor General of Canada. 2016. Report 2: Mitigating the Impacts of Severe Weather. Accessed at: http://www.oag-bvg.gc.ca/internet/English/parl_cesd_201605_02_e_41381.html

10 Parliamentary Budget Officer of Canada. 2016. Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events. Accessed at: www.pbo-dpb.gc.ca/web/default/files/Documents/Reports/2016/DFAA/DFAA_EN.pdf

11 Insurance Bureau of Canada. 2015. Facts of the Property and Casualty Insurance Industry in Canada 2015. Accessed at: www.assets.ibc.ca/Documents/Facts%20Book/Facts_Book/2015/Fact-Book-2015.pdf

12 Business News Network. 2017. Half of Working Canadians "Overwhelmed" by Debt and Living Paycheque to Paycheque: Survey. Accessed at: www.bnnbloomberg.ca/half-of-working-canadians-overwhelmed-by-debt-and-living-paycheque-to-paycheque-survey-1.562284

13 Moody's Investors Service. 2017. Environmental Risks – Evaluating the Impact of Climate Change. Accessed at: www.southeastfloridaclimatecompact.org/wp-content/uploads/2017/12/Evaluating-the-impact-of-climate-change-on-US-state-and-local-issuers-11-28-17.pdf

Standards & Poor's Ratings Services. 2015. How Environmental and Climate Risks Factor into Global Corporate Ratings. Accessed at: www.environmental-finance.com/assets/files/How%20Environmental%20And%20Climate%20Risks%20Factor%20Into%20Global%20Corporate%20Ratings%20Oct%2021%202015%20(2).pdf

14 Climate Disclosure Project (CDP). 2015. How CDP Data Can Inform Investors about Risk and Opportunities in U.S. Municipal Bonds. Accessed at: b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/001/613/original/White-paper-muni-bonds.pdf?1486720635

15 Moody's Investors Service. 2017. Environmental Risks – Evaluating the Impact of Climate Change. Accessed at: www.southeastfloridaclimatecompact.org/wp-content/uploads/2017/12/Evaluating-the-impact-of-climate-change-on-US-state-and-local-issuers-11-28-17.pdf

16 Ibid.

17 Canadian Investment Review. 2017. Climate Change and Credit Risk. Accessed at: www.investmentreview.com/analysis-research/climate-change-and-credit-risk-8023?Print

18 Globe and Mail. 2015. Leaky basement lawsuit drags on in Maple Ridge. Accessed at: www.theglobeandmail.com/news/british-columbia/leaky-basement-lawsuit-drags-on-in-maple-ridge/article25051951/

19 Hutton, D. 2004. Psychosocial effects of a natural disaster: A post-flood assessment in Red River Valley. Environments, 32(2), 27-43

20 Santé Montréal. 2017. Montréal's Director of Public Health presents findings from the health survey flood victims. Accessed at: santemontreal.qc.ca/en/public/inondations-printanieres-2017/

21 Hutton, D. 2004. Psychosocial effects of a natural disaster: A post-flood assessment in Red River Valley. Environments, 32(2), 27-43

22 Sahni, V., Scott, A. N., Beliveau, M., Varughese, M., Dover, D. C., & Talbot, J. 2016. Public health surveillance response following the southern Alberta floods, 2013. Can J Public Health, 107(2), 142–148

23 Santé Montréal. 2017. Montréal's Director of Public Health presents findings from the health survey flood victims. Accessed at: santemontreal.qc.ca/en/public/inondations-printanieres-2017/

24 Intact Centre on Climate Adaptation. 2018. After the Flood: The Impact of Climate on Mental Health and Lost Time From Work. Accessed at: www.intactcentreclimateadaptation.ca/wp-content/uploads/2018/06/After-The-Flood.pdf

25 Waters, Darren, Watt, W. Edgar, Marsalek, Jiri and Anderson, Bruce C. 2003. Adaptation of a Storm Drainage System to Accommodate Increased Rainfall Resulting from Climate Change. Journal of Environmental Planning and Management, 46:5, 755 – 770.

26 Red River Basin Commission. Accessed at: www.redriverbasincommission.org/

27 Engineers Canada. Public Infrastructure Engineering Vulnerability Committee (PIEVC). PIEVC Engineering Protocol. Accessed at: https://pievc.ca/protocol

28 The Association of Professional Engineers and Geoscientists of BC (APEGBC). Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC. Accessed at: https://www.egbc.ca/getmedia/18e44281-fb4b-410a-96e9-cb3ea74683c3/APEGBC-Legislated-Flood-Assessm; Public Safety Canada. Federal Floodplain Mapping Guidelines Series. Accessed at: www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/fldpln-mppng-en.aspx

29 Public Safety Canada. Federal Floodplain Mapping Guidelines Series. Accessed at: www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/fldpln-mppng-en.aspx

30 Public Safety Canada. Critical Infrastructure. Accessed at: https://www.publicsafety.gc.ca/cnt/ntnl-scrt/crtcl-nfrstrctr/index-en.aspx

31 Federation of Canadian Municipalities. 2018. Guidebook: How to develop an asset management policy and strategy. Accessed at: https://fcm.ca/home/programs/municipal-asset-management-program/guidebook-develop-an-asset-management-policy-and-strategy.htm

32 EPCOR. 2018. SIRP: Flood Mitigation Impacts. Market Research Report. Accessed at: www.epcor.com/products-services/drainage/Documents/EPCOR_SIRP_OCt2018_ResearchReport.pdf

33 Modified. EPCOR. 2018. Flood Mitigation. Accessed at: www.epcor.com/products-services/drainage/Pages/flood-mitigation.aspx

34 Government of Canada. Vulnerable Populations. Accessed at: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/environmental-contaminants/vulnerable-populations.html

35 Red Cross Canada. 2017. Integrating Emergency Management and High-Risk Populations: Survey Report and Action Recommendations. Accessed at: www.redcross.ca/crc/documents/3-1-4-2_dm_high_risk_populations.pdf

36 City of Toronto. 2018. Wellbeing Toronto. Accessed at: https://goo.gl/cKchPU

37 Government of Canada. 2016. Canada's Way Forward on Climate Change: The Paris Agreement. Accessed at: www.canada.ca/en/environment-climate-change/services/climate-change/paris-agreement.html

38 Government of Canada. 2017. Sendai Framework for Disaster Risk Reduction (DRR) 2015–2030. Accessed at: www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/pltfrm-dsstr-rsk-rdctn/snd-frmwrk-en.aspx

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