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INVESTING IN CANADA'S FUTURE:

The Cost of Climate Adaptation at the Local Level

FINAL REPORT - FEBRUARY 2020

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Green Analytics Corp. was commissioned by the Federation of Canadian Municipalities (FCM) and Insurance Bureau of Canada (IBC) to establish a credible estimate of investment in climate change disaster adaptation infrastructure to reduce the cost of climate change in Canada.

Executive Summary

Climate change is increasing the frequency and severity of extreme weather events across Canada. In 2019, the federal government released the report *Canada's Changing Climate*. It found that the annual average temperature in Canada has increased by 1.7°C since 1948, with higher temperature increases in Canada's North, the Prairies and northern British Columbia. While every region in Canada experiences the impacts of the warming climate differently, evidence indicates an increase in the severity of heat waves and drought, more frequent and intense rainfall events, changes in snow and ice cover, and more frequent and intense storm surges in coastal regions. For Canada and its economy, the consequences are severe. While a number of studies have attempted to measure the cost of climate change in terms of the damage it will cause or the impact it will have on the economy, there is more to be done to estimate the cost of adapting to climate change.

Climate change adaptation, or disaster mitigation, means taking strategic actions to reduce a community's vulnerability to the impacts of climate change. In the past decade, climate adaptation in Canada has progressed from research, to public engagement, to actions to reduce the impacts of climate change. All levels of government have developed climate change adaptation strategies and are investing in specific adaptation measures. The Federation of Canadian Municipalities (FCM) and Insurance Bureau of Canada (IBC) commissioned Green Analytics to establish a credible estimate of the investment in municipal infrastructure and local adaptation measures needed to reduce the impacts of climate change in Canada.

Municipalities, as the owners and operators of 60% of the public infrastructure in Canada, are on the frontlines of both the impacts of climate change and the solutions to protect Canadians. However, addressing climate risks by retrofitting existing infrastructure and implementing new adaptation measures poses an additional burden on the limited financial capacity of municipalities. Municipalities cannot shoulder the cost of adapting to climate change alone. Climate change adaptation is a shared responsibility among all orders of government, and will require a long-term commitment to action. This study is the first attempt to estimate the long-term need for investment in climate change adaptation measures at the local level.

METHODOLOGY:

To estimate how much investment is required to help communities adapt to climate change and reduce disaster risk, Green Analytics collected adaptation cost estimates for a variety of communities across Canada and housed those estimates in an adaptation cost database. The estimates were based on vulnerability and risk assessments done at the local level, usually by a municipality. The adaptation cost estimates were adjusted to allow them to be compared between communities and added up at the national level. Other information in the database for each adaptation cost estimate includes location, such as province or territory; infrastructure type, such as buildings, green infrastructure, roads and water treatment; and climate risk, such as drought, erosion, flood, heat wave and wildfire. The final database contained 414 adaptation cost estimates for 34 communities across the country. For each community, the gross domestic product (GDP) values were obtained or established and added to the database. The cost of adapting to climate change was then determined relative to the size of the local economy, expressed as a percentage of local GDP.

Finally, the adaptation cost as a percentage of local GDP collected for each community within a region of the country (West, Prairies, North, Central, East) was analyzed to determine the average percentage for that region. The five regional percentages were then weighted by the region's respective share of the national GDP. Combined, these regional results were added together to obtain a national estimate of the cost of adaptation as a percentage of national GDP.

RESULTS:

The analysis determined that an average annual investment in municipal infrastructure and local adaptation measures of $5.3 billion is needed to adapt to climate change. In national terms, this represents an annual expenditure of 0.26% of GDP. This estimate represents the total annual cost of the actions that need to be taken at the local level for public infrastructure. These investments would typically be cost-shared between each order of government. Given the scale of the long-term cost of adapting to climate change, public funding may need to be leveraged by new forms of private capital. Flood, erosion and permafrost melt are associated with the highest cost as a percentage of GDP at 1.25%, 0.12% and 0.37%, respectively. These climate risks require the greatest investment in adaptation. From an infrastructure perspective, buildings, dikes and roads require the greatest investment in adaptation; they are associated with the highest costs as a percentage of GDP at 2.01%, 1.18% and 0.47%, respectively. Grey infrastructure has the highest average cost at 0.75%, green infrastructure has an average cost of 0.05% and soft infrastructure (or administrative action) has an average cost of 0.03%. From a regional perspective, Canada's East, at 3.20%, and North, at 0.37%, have higher average costs. The four highest costs as a percentage of GDP in the database are coastal communities in Eastern Canada.

The results of this research, finding an annual average investment equivalent to 0.26% of national GDP, generally align with historical investments made by leading cities outside of Canada, and with international research on future needs. In 2014-15, the cities of London, New York and Paris spent approximately 0.22% of their respective GDP on public and private expenditures on climate change adaptation. Looking forward, an international assessment concluded that countries should be spending between 0.60% and 1.25% of GDP on adaptation measures to minimize the worst impacts of climate change across sectors of the economy, including but not limited to municipally owned infrastructure.

This research is the first attempt to quantify what Canadian governments need to be spending on local disaster mitigation and adaptation projects to reduce the impacts of climate change. In releasing this report, IBC and FCM hope to contribute to the growing body of knowledge on climate change adaptation in the Canadian context. The cost of climate change adaptation will continue to be better understood as more data on adaptation investments becomes available and additional research along these lines is undertaken. While better data and additional research will further clarify long-term costs, what this research clearly shows is that an ambitious long-term climate adaptation investment plan—including infrastructure funding commitments and efforts to improve local capacity to better assess climate risk as called for by both IBC and FCM—is urgently needed now.

SECTION 1

Introduction

The cost of climate change is rising in Canada. The Government of Canada's 2019 report, *Canada's Changing Climate*, documenting the latest evidence of a changing climate, found that the annual average temperature in Canada increased by 1.7°C since 1948, when nation-wide records became available. Higher temperature increases have occurred in Canada's North, the Prairies and northern British Columbia. While regions in Canada experience impacts of a warming climate differently, evidence indicates an increase in the severity of heatwaves and drought, more intense rainfall events, changes in snow and ice cover and greater storm surges in coastal regions. The 2019 report concluded that trends of more frequent and intense weather extremes will continue, increasing flood and wildfire risks, among other impacts.[1] The potential consequences to the well-being of Canadians and our economy are severe.

Public infrastructure is particularly vulnerable to impacts from climate change as municipalities in Canada struggle with the cost of maintaining these crucial assets. As of 2016, one-third of Canadian municipal infrastructure was considered to be in fair, poor or very poor condition.[2] However, research is showing that investments in adaptation and risk mitigation measures can help ensure Canadian communities are resilient to threats caused by a changing climate, including risks to our public infrastructure. Some studies have shown a return on investment around 6:1, meaning that for every dollar invested in mitigation measures, $6 is saved in future damages.

Given the benefits of investing in disaster mitigation and adaptation, what is the level of investment that federal, provincial/territorial, and municipal governments should be making? International research of investment rates in climate adaptation measures in the United States, United Kingdom and the European Union suggests that national governments need to be investing 0.66-1.25% of GDP in adaptation measures to minimize the worst impacts of extreme weather events.[3] As a percentage of Canada's GDP in 2018, this would be $13.5-$25.6 billion per year. However, a national level study of investment on adaptation measures in Canada is currently lacking, both in terms of how much Canada is already spending on adaptation and how much Canada should be spending. The goal of this research project was therefore to start to answer the latter question and gain a better understanding of the level of investment needed for disaster mitigation and climate change adaptation measures in Canada.

[1] Warren, F.J. and Lemmen, D.S., editors, 2014, Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON.
[2] Canadian Infrastructure Report Card, 2016, available at: http://canadianinfrastructure.ca/downloads/Canadian_Infrastructure_Report_2016.pdf
[3] Martinez-Diaz, L., 2018, Investing in resilience today to prepare for tomorrow's climate change. Bulletin of the Atomic Scientists, 74:22, pp. 66-72.

What is Climate Change Adaptation?

Adaptation is any alteration in the structure or function of something or any of its parts that makes it better suited for its environment. In the context of climate change, this means adjusting to projected or actual changing climates to become more resilient to those changes. While there are numerous working definitions of climate adaptation,[4,5,6] the common theme is that adaptation is a response to climate impacts. Many definitions also recognize the intent of adaptation, which is to reduce the negative effects of climate change. The European Commission and European Environment Agency differentiate between three types of adaptation: grey, green and soft. Grey adaptation focuses on human-made physical infrastructure such as dikes, sea walls, expanded water treatment capacity and fire-resistant building materials. Green adaptation includes protecting, strengthening and modifying natural systems such as wetlands, mangroves, forests and soil nutrition. Soft adaptation, on the other hand, focuses on legal, socio-cultural, political and financial management policies and systems that enable adaptation.[7] Climate adaptation is unique from climate change mitigation, which focuses on activities that reduce or eliminate the release of greenhouse gases that contribute to climate change.[8]

SECTION 3

Why is Climate Change Adaptation Needed?

To date, the majority of efforts to combat climate change have focused on the mitigation side, reducing or eliminating the release of greenhouse gases that contribute to climate change itself. However, as the 2019 *Canada's Changing Climate* report demonstrates, communities in Canada are already facing the impacts of climate change and so while adaptation can have many benefits, including employment, reduced energy costs, improved air and water quality, and improved livability,[9] one of the main benefits is avoiding the high cost of the predicted climate change impacts.

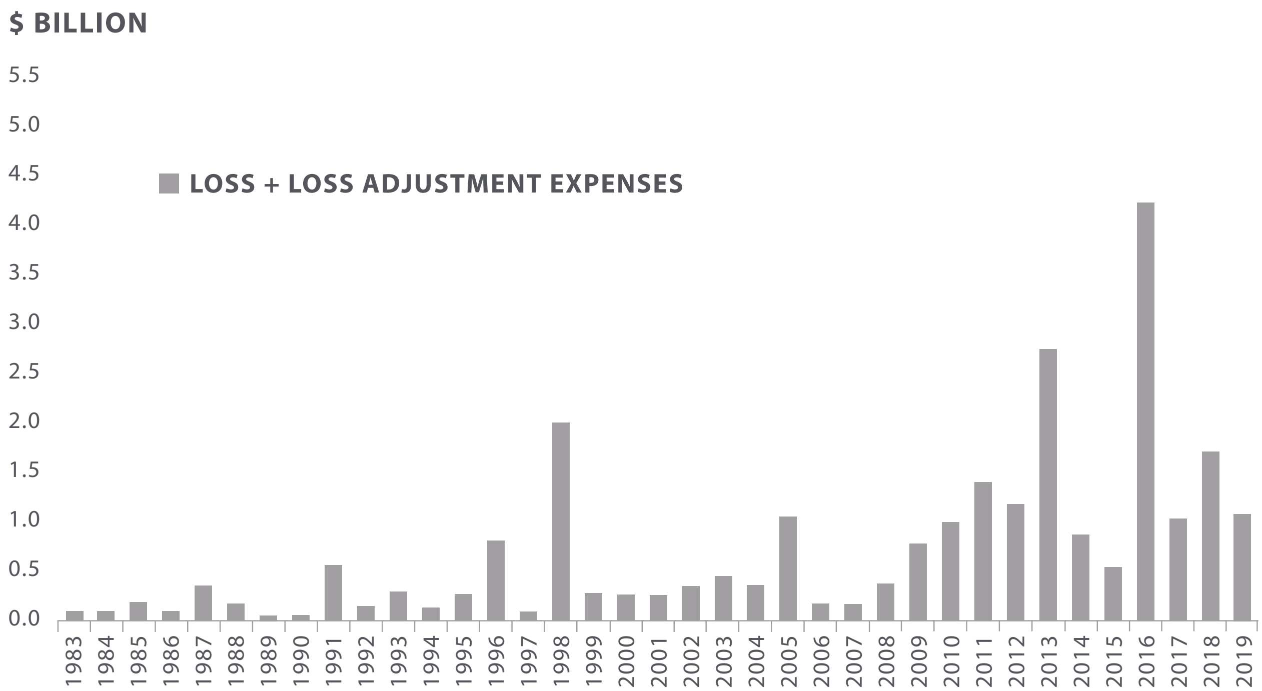
3.1 COSTS OF CLIMATE CHANGE

In 2011, the National Round Table on Environment and Economy (NRTEE) estimated the economic impacts of climate change for Canada to be $5 billion per year by 2020 and between $21 billion and $43 billion per year by 2050, assuming a global warming scenario of slightly under 2°C. That report, however, only focused on three key areas–flooding damages to coastal dwellings resulting from climate change–induced sea level rise and storm surges, timber supply impacts through changes in pests and fires, and health care system costs due to poorer air quality in Toronto, Montreal, Vancouver and Calgary.[10] A more comprehensive assessment of the current costs of climate change given more recent knowledge and data is likely to be much higher.

[4] Feltmate, B. and J. Thistlewaite, Climate Change Adaptation: A Priorities Plan for Canada, Report of the Climate Change Adaptation Project (Canada).
[5] IPCC, 2007, Climate Change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.
[6] Warren, F.J. and Lemmen, D.S., 2014, Synthesis. In F.J. Warren and D.S. Lemmen (Eds.), Canada in a changing climate: Sector perspectives on impacts and adaptation, Ottawa, ON: Government of Canada.
[7] Climate-ADAPT, 2018, Adaptation Options. European Commission and European Environment Agency. Retrieved from: https://climate-adapt.eea.europa.eu/knowledge/adaptation-information/adaptation-measures
[8] Feltmate, B. and J. Thistlewaite, Climate Change Adaptation: A Priorities Plan for Canada, Report of the Climate Change Adaptation Project (Canada).
[9] City of Surrey, City of Surrey Climate Adaptation Strategy.
[10] National Round Table on Environment and Economy. 2011. Paying the Price: The Economic Impacts of Climate Change for Canada.

Now that the original forecast date of 2020 has been reached, support for this significant estimate by the NRTEE can be seen in the data on insurance payouts and disaster financial assistance. Insurance Bureau of Canada (IBC) reports insurable losses dating back to 1983. The time series data in Figure 1 clearly indicates a rising trend in insurance payouts as a result of natural disasters. For nine of the last ten years (2010-2019), insurance payouts for catastrophic losses from natural disasters have exceeded $1 billion per year. For the 26 years prior to 2009, insurable payouts averaged $400 million per year.

FIGURE 1. CATASTROPHIC INSURED LOSSES FROM NATURAL DISASTERS, 1983 TO 2019 (VALUES IN 2019 CAN$)

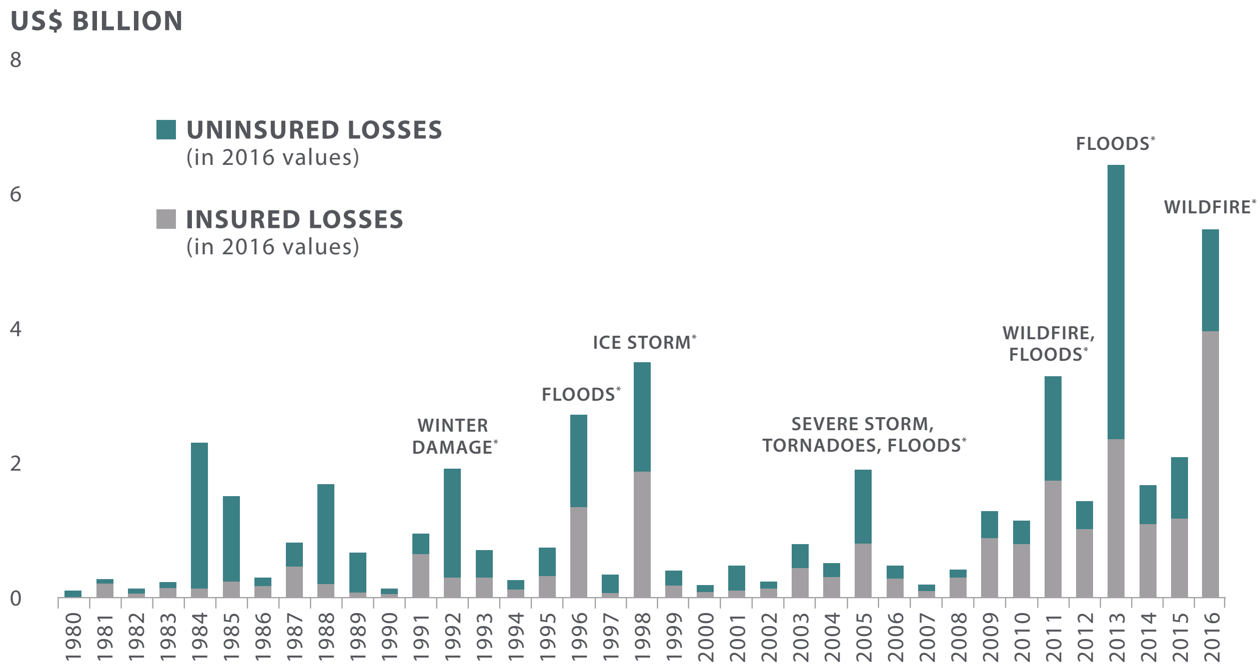


*Insured losses for a given disaster are deemed catastrophic when they total $25 million or more.
Catastrophic losses for a year are the sum total of insured losses from these natural disasters.
Source: Insurance Bureau of Canada

However, insured losses only account for a portion of the full costs attributed to catastrophic weather-related events. An accepted standard for capital losses is for every dollar of losses borne by insurers in Canada, $3-4 are borne by governments, households and businesses.[11] The spread will vary depending on the type of catastrophic event. For example, insurance policies are less likely to cover flood protection versus fire protection.[12] The spread of losses borne by governments, households and businesses would be even greater if indirect costs were included. Figure 2 provides an example of the additional costs associated with uninsurable losses from catastrophic events in Canada.

[11] Moudrak, N., Feltmate, B., Venema, H., Osman, H. 2018. Combating Canada's Rising Flood Costs: Natural infrastructure is an underutilized option. Prepared for Insurance Bureau of Canada. Intact Centre on Climate Adaptation, University of Waterloo.
[12] Moudrak, N.; Feltmate, B. 2017. Preventing Disaster Before It Strikes: Developing a Canadian Standard for New Flood-Resilient Residential Communities. Prepared for Standards Council of Canada. Intact Centre on Climate Adaptation, University of Waterloo.

FIGURE 2. CATASTROPHIC LOSSES FROM NATURAL DISASTERS, 1980-2016 (VALUES IN US$2016)



*costliest event(s) in the respective year
Source: From Moudrak, N.; Feltmate, B. 2017. Based on 2017 Munich Re, Geo Risks Research, NatCatSERVICE. As of February 2017.

Evidence of the growing cost of climate change in Canada is also demonstrated by the trend in government sponsored disaster relief payments. The rising severity of extreme weather events has led to a significant increase in provinces and territories seeking assistance under the federal Disaster Financial Assistance Arrangements (DFAA) program. The program was set up in 1970 to help provinces and territories recover from natural disasters. The Office of the Auditor General Canada reports that from 2009 to 2015, DFAA's compensation to the provinces and territories was greater than the previous 39 fiscal years combined.[13] The fund's payouts for the past five years (2013-2014 to 2017-2018) totalled $3.3 billion.[14] The increase in DFAA costs over the past 10 years is attributed to more extreme weather events with greater intensity.[15] Recognizing its escalating liability associated with the DFAA program, in 2015 the Government of Canada changed the expense thresholds at which federal funding is triggered (Table 1). These threshold changes reduce the share of disaster-related recovery costs borne by the federal government and shift those costs to municipal and provincial governments, homeowners and businesses in impacted regions.[16]

[13] Office of the Auditor General Canada. 2016. Spring 2016 Reports of the Commissioner of the Environment and Sustainable Development, Report 2: Mitigating the Impacts of Severe Weather Events. Also reported in Moudrak et al., 2018.
[14] Parliamentary Budget Officer of Canada. 2016. Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events.
[15] Parliamentary Budget Officer of Canada. 2016. Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events.
[16] Public Safety Canada. 2019. Guidelines for the Disaster Financial Assistance Arrangements (DFAA). [online] Available at: https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/gdlns-dsstr-ssstnc/index-en.aspx

TABLE 1. DISASTER FINANCIAL ASSISTANCE ARRANGEMENTS PROGRAM ($DOLLARS)

DFAA ASSISTANCE PRIOR TO FEBRUARY 2015	DFAA THRESHOLD LEVELS AS OF JANUARY 2019	FEDERAL SHARE	PROVINCIAL SHARE
$0 to $1	$0 to $3.19	0%	100%
$1 to $3	$3.19 to $6.39	50%	50%
$3 to $ 5	$6.39 to $ 12.78	75%	25%
$5 plus	$12.78 plus	90%	10%

Source: Public Safety Canada. 2019.

A 2016 report by the Parliamentary Budget Officer (PBO) projected the costs for disaster financial assistance arrangements due to weather events for 2016 to 2020 at $4.9 billion of which DFAA would cover $902 million, or 18%. The analysis considered hurricanes, floods, convective storms (hail, rain and wind) and winter storms. Wildfires, which can be a result of dry weather associated with climate change and can trigger DFAA support, were not included. Floods accounted for the largest percentage of the projected annual DFAA costs at $673 million (Table 2).

TABLE 2. PROJECTED AVERAGE ANNUAL LOSSES, 2016-2020 ($MILLIONS)

WEATHER EVENT	PROJECTED ANNUAL LOSS	DFAA PORTION
Hurricanes	$98.7	$19.0
Convective storms	$671	$1.83
Winter storms	$1,720	$208
Floods	$2,430	$673
Total	**$4,920**	**$902**

Source: Parliamentary Budget Officer of Canada. 2016.

As part of the report, the PBO also completed a historical assessment of cumulative losses and DFAA and insurance payments from extreme weather events for the period 2005 to 2014. Total cumulative losses were estimated to be $31 billion, of which 16% were covered by DFAA and 47% were covered by insurance payments. It can therefore be inferred that the outstanding $11 billion in losses (37%) were borne by households, businesses, and municipal and provincial governments in affected regions (Table 3).[17]

[17] Parliamentary Budget Officer of Canada. 2016. Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events.

TABLE 3. CUMULATIVE LOSSES, DFAA AND INSURANCE PAYMENTS (2005-2014) ($MILLIONS 2014)

	FLOODS		CONVECTION STORMS		HURRICANES		WINTER STORMS		TOTAL	
	LOSSES	% OF TOTAL	LOSSES	% OF TOTAL	LOSSES	% OF TOTAL	LOSSES	% OF TOTAL	LOSSES	% OF TOTAL
Total loss	$12,505	100%	$7,314	100%	$718	100%	$10,452	100%	**$30,989**	**100%**
DFAA	$3,465	28%	$20	0%	$138	19%	$1,267	12%	**$4,890**	**16%**
Insurance	$4,982	40%	$5,726	78%	$436	61%	$3,552	34%	**$14,696**	**47%**
Outstanding	$4,058	32%	$1,568	21%	$144	20%	$5,633	54%	**$11,403**	**37%**

Source: Parliamentary Budget Officer of Canada. 2016.

While cost assessments of extreme weather events typically report insurable losses and/or direct capital losses only, damages to infrastructure cascade into other losses. As an example, productivity losses resulting from damaged infrastructure are substantial. A 2016 economic analysis of the cost of flooding in Canada estimated productivity losses ranging from 27% to 42% of capital costs depending on the severity of the flooding event and length of recovery period.[18]

Statistics Canada completed a detailed analysis on the impact of flooding in Southern Alberta in June 2013 on hours worked in the province. The analysis found that during the last two weeks in June, 300,000 Albertans (or 13.5% of the employed population in Alberta) working in the private sector lost 7.5 million hours of work due to workplace closures because of the flood event.[19] Damages to infrastructure caused by extreme weather events can hinder broader economic activity that is not captured by replacement cost estimates. When such costs are taken into account, adaptation measures become even more justifiable.

Not surprisingly, given the trends presented above, the rising occurrence of extreme weather events attributed to climate change is leading to higher costs for municipal insurance policies. Henstra and Thistlewaite (2017) note that increased premiums, higher deductibles and changes to municipal insurance policies limiting liability followed the large insured and uninsured losses in 2013. As examples, the authors reference the Toronto and Calgary municipal policies. The Toronto policy (2015) cost $5.1 million with a deductible of $5 million providing $100 million in liability coverage and $1.8 billion for property damage. Calgary's policy, after the 2013 flood event, included a loss limit of $700 million for damage to property, with a deductible of $2 million.[20] In Ontario between 2007 and 2016, municipal liability premiums increased by 22.2% to account for increased liability coverage.

Home policies are going up as well. Climate change was cited as the reason for insurance companies across Canada increasing home insurance rates for 2019 by 5-10% on top of inflation. In addition, premiums and deductibles for sewer backup and overland flood insurance have also increased.[21] Elsewhere, insurers have warned that climate change may make insurance coverage for most people unaffordable. This proclamation came after $24 billion in losses resulted from wildfires in California.[22]

[18] Davies, J. 2016. Economic analysis of the costs of flooding. Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 41:1-2, 204-219.
[19] Government of Alberta, Alberta Enterprise & Advanced Education. 2013. Impact of Southern Alberta Flooding on Hours Worked and GDP. Alberta Government Economic Commentary. Available online: www.albertacanada.com/files/albertacanada/SP-Commentary_09-06-13.pdf .
[20] Henstra, D., and Thistlewaite, J. 2017. Climate Change, Floods, and Municipal Risk Sharing in Canada. Munk School of Global Affairs (UoT). [online] Available at: https://munkschool.utoronto.ca/imfg/uploads/373/1917_imfg_no_30_online_final.pdf
[21] Osental, D. 2019. Broker points to climate change as reason for rising home insurance rates. Insurance business industry magazine. 2019.
[22] https://www.theguardian.com/environment/2019/mar/21/climate-change-could-make-insurance-too-expensive-for-ordinary-people-report

3.2 BENEFITS OF CLIMATE CHANGE ADAPTATION

With the evidence piling up on the actual and predicted costs of climate change, the benefit of climate adaptation in reducing those costs becomes very important. The 2016 Office of the Auditor General's report on federal government support for mitigating the effects of severe weather notes the potential cost effectiveness of disaster mitigation measures for government and society, citing Public Safety Canada's estimate that every dollar invested in mitigation in Canada saves $3 to $5 in recovery costs. As an example, the report notes the $63 million invested to build the Manitoba Red River Floodway in 1960, which is estimated to have saved $8 billion by 2008 in avoided flood recovery costs.[23] In 2017/2018 the US National Institute of Buildings Sciences looked at the results of 23 years of federally funded mitigation grants provided by the Federal Emergency Management Agency (FEMA), U.S. Economic Development Administration (EDA) and U.S. Department of Housing and Urban Development (HUD) and found mitigation funding can save the nation $6 in future disaster costs, for every $1 spent on hazard mitigation.[24]

The NRTEE (2011) found that adaptation strategies are cost, effective ways to reduce the economic impacts of climate change ranging in a benefit-to-cost ratio of 38:1 under a high climate change, high growth scenario, to 9:1 under a low climate change, slow growth scenario. In coastal areas, for example, prohibiting new construction in areas at risk of flooding as well as undertaking strategic retreat by gradually abandoning dwellings once flooded, reduces the costs of climate change to only 3-4% of what the costs would have been without adaptation. The NRTEE also found that the cost to build a new house, bridge or transmission line that is adapted to climate change for its lifecycle only adds 0-5% to the construction costs. This is significantly cheaper than retrofitting buildings, or restoring or rebuilding infrastructure post-damage. The 0-5% addition to the construction cost range is generally recognized as a rule of thumb for the cost of incorporating adaptation initiatives into the design of a new structure.

Demonstrating the value of administrative adaptation measures (or soft infrastructure), Green Analytics estimated the value of Ontario flood plain regulations (Section 28 of the Conservation Authorities Act).[25] The study drew on evidence from a study of the potential impact of flooding on the City of Waterloo prepared by the Intact Centre for Climate Adaptation. The Intact analysis examined the expected property damage to the 333 structures located within the Regulatory Laurel Creek floodplain resulting from a flood proportionate to Hurricane Hazel. The projected direct damages to these buildings was estimated at $85 million.[26] A subsequent analysis of productivity losses associated with a Hurricane Hazel flood of Laurel Creek assuming a six-month recovery period estimated such losses at $17 million.[27]

Green or natural infrastructure also holds significant promise as an adaptation measure to reduce the cost of climate impacts. Green infrastructure is often considered an umbrella term that includes natural infrastructure (wetlands, forests, shorelines), enhanced natural infrastructure (bioswales, rain gardens, urban parks) and engineered infrastructure (green roofs, rain barrels, permeable pavement).[28] Research confirms that investments in natural infrastructure in particular is an effective adaptation strategy. For example, a study by the Intact Centre on Climate Adaptation demonstrated that natural

[23] Office of the Auditor General of Canada. 2016.
[24] National Institute of Building Sciences. 2018. Natural Hazard Mitigation Saves: 2018 Interim Report. Retrieved from: https://www.nibs.org/page/mitigationsaves
[25] Green Analytics, 2018, Economic Benefits of Floodplain Regulation. A report prepared for the Ontario Ministry of Natural Resources.
[26] Moudrak, N.; Hutter, A.M.; Feltmate, B. 2017. When the Big Storms Hit: The Role of Wetlands to Limit Urban and Rural Flood Damage. Prepared for the Ontario Ministry of Natural Resources and Forestry.
Intact Centre on Climate Adaptation, University of Waterloo.
[27] Green Analytics, 2019, Productivity Analysis of Floodplain Regulation. A report prepared for the Ontario Ministry of Natural Resources.
[28] Municipal Natural Assets Initiative, 2017, Defining and Scoping Municipal Natural Assets

wetlands can reduce the costs of flood damage by 29% in rural areas and 38% in urban areas.[29] The community of Gibsons, BC, recognizing the importance of their natural infrastructure, was the first municipality in North America to declare natural infrastructure assets as municipal assets.[30] The town then committed to operate and maintain its natural assets in the same manner as storm sewers, roads and other traditional engineered assets.[50] An assessment of the naturally occurring ponds in the town's White Tower Park found that the ponds provided the same stormwater management services as engineered assets that would have cost about $3.5 million to $4 million to construct. These assessments led Gibsons to protect its ponds from proposed new housing developments in order to save the capital costs of constructing engineered stormwater infrastructure. Other Canadian communities are now following suit, adapting the framework initiated by Gibsons and developed through the Municipal Natural Assets Initiative (MNAI) and employing green infrastructure as an adaptation strategy.

3.3 CLIMATE CHANGE ADAPTATION IN CANADA

Climate adaptation is increasing in the country as it has been recognized as a necessary response to climate change; one that enhances the resilience of Canadians to climate change impacts.[31] Experience in Canada clearly demonstrates that there is a solid awareness in the country of the impacts of climate change and the need to adapt. There is also increasing evidence that resources are being mobilized and capacity is building to adapt through various federal, provincial, territorial and local government adaptation plans as well as consortiums and collaborative efforts related to adaptation (e.g., Pacific Climate Impacts Consortium).

As an example, in response to the urgent need for adaptation measures to protect municipal infrastructure, 23 Canadian municipalities are part of ICLEI Canada's Building Adaptive and Resilient Communities (BARC) program. The program provides a framework and comprehensive planning methodology to support municipalities in developing and implementing climate change adaptation plans.[32] Climate change impacts that ranked highest among BARC member municipalities that have completed climate adaptation plans include:

- More frequent freezing and thawing causing damage to roads, sidewalks, bridges and stormwater ponds.
- Overburdened stormwater systems caused by intense precipitation events.
- Damage to transportation infrastructure and public property due to flooding.
- Damage to electrical distribution systems and parks and greenspaces as a result of more severe storms.

Among the BARC program municipalities that have completed climate adaptation plans, all recognize the exposure of public infrastructure to climate change impacts as a rationale for adaptation measures and strong action.

[29] Moudrak, N.; Hutter, A.M.; Feltmate, B. 2017. When the Big Storms Hit: The Role of Wetlands to Limit Urban and Rural Flood Damage. Prepared for the Ontario Ministry of Natural Resources and Forestry. Intact Centre on Climate Adaptation, University of Waterloo.
[30] Town of Gibsons, Towards an Eco-Asset Strategy in the Town of Gibsons. Retrieved from: https://mnai.ca/media/2018/01/EcoAsset_Strategy.pdf
[31] Warren, F.J. and Lemmen, D.S., editors, 2014, Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON.
[32] ICLEI. BARC Program.[online] Available at: http://icleicanada.org/programs/adaptation.

Progress is less evident in the implementation of adaptation measures.[33] According to the most recent national assessment of *Climate Change Adaptation*, the majority of adaptation measures assessed in Canada involved research, monitoring, assessing vulnerabilities and opportunities, developing strategies and mainstreaming adaptation within existing policies and planning. The balance of the measures were implemented to prevent or offset harm from climate-related risks.[34] Table 4 summarizes some of the main federal adaptation efforts, while Table 5 provides examples of provincial and municipal structural adaptation implementation.

TABLE 4. EXAMPLES OF FEDERAL ADAPTATION ACTIVITIES

TITLE	DESCRIPTION
Pan-Canadian Framework on Clean Growth and Climate Change	The federal government's climate change plan, developed with the provinces, territories and Indigenous Peoples. The plan describes emission reduction and resilient building initiatives including climate adaptation actions.[35]
Federal Adaptation Policy Framework	This framework guides domestic action by the Government of Canada to address adaptation to the impacts of climate variability and change. It sets out a vision for adaptation in Canada, objectives, roles of the federal government and provides criteria for setting priorities for action.[36]
Arctic Policy Framework	Looking ahead to the year 2030, the framework will guide the federal government's involvement in the North, including supporting adaptation action.
Emergency Management Strategy for Canada: Towards a Resilient 2030	The strategy is a collaborative, whole-of-society roadmap to strengthen Canada's ability to assess risks, prevent/mitigate, prepare for, respond to and recover from disasters.
Canada's Climate Change Adaptation Platform	Established in 2012, Canada's Climate Change Adaptation Platform is a national forum that brings together key groups in Canada to collaborate on climate change adaptation priorities. Members include representatives from federal, provincial, and territorial governments, industry, communities, academics, and Indigenous, professional, and not-for-profit organizations.[37]
Disaster Mitigation and Adaptation Fund (DMAF)	Funding for built and natural, large-scale infrastructure projects that help build the resilience of infrastructure to natural disasters, extreme weather events and climate change.
National Disaster Mitigation Program (NDMP)	Budget 2014 earmarked $200 million over five years, from 2015 to 2020, to establish the NDMP. The NDMP addresses rising flood risks and costs, and builds the foundation for informed mitigation investments that could reduce, or even negate, the effects of flood events.[38]
Climate-Resilient Buildings and Core Public Infrastructure Initiative	This initiative will develop capacity in Canada's construction industries to adapt to the demands on built infrastructure attributed to climate change. The program is intended to drive innovation and provide partners with the knowledge and tools they need to make sound decisions about how to design, operate, and maintain their infrastructure assets.[39]

[33] Warren, F.J. and Lemmen, D.S., editors, 2014, Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON.
[34] Warren, F.J. and Lemmen, D.S., editors, 2014, Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON.
[35] https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html
[36] https://www.canada.ca/en/environment-climate-change/services/climate-change/federal-adaptation-policy-framework.html
[37] https://www.nrcan.gc.ca/climate-change/impacts-adaptations/adapting-our-changing-climate/10027
[38] https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-en.aspx
[39] https://www.infrastructure.gc.ca/plan/crbcpi-irccipb-eng.html

TABLE 5. EXAMPLES OF PROVINCIAL/TERRITORIAL AND MUNICIPAL ADAPTATION EFFORTS

LOCATION	DESCRIPTION
Halifax, NS	The Municipal Planning Strategy and Land Use By-Law for the downtown Halifax waterfront area prescribes minimum elevation for any ground-floor development – to protect against sea level rise and flooding.[40]
Surrey, BC	To help their coastal communities become more resilient, the city is developing a Coastal Flood Adaptation Strategy (CFAS) for Surrey's coastal floodplain area. The flood adaptation measures will increase flood resilience and protect over 125,000 commuters, residents, homes and businesses who are at high risk of coastal flooding.
Ottawa, ON	Norman Wells Airport and Ottawa International Airport have grooved their runways to improve traction and drainage during heavy precipitation. [41]
British Columbia	British Columbia provincial guidelines for development in flood-risk areas identify the need for Flood Construction Levels in line with the increased risk presented by sea-level rise. [42]
Northwest Territories	The Northwest Territories Housing Corporation is adapting housing construction to protect against melting permafrost through the use of new foundation systems (e.g., using larger diameter and deeper pile installations) designed to better respond to and absorb the additional stress caused by shifts in the ground beneath buildings. The use of thermosyphons (that keep permafrost cold through passive heat exchange) and other technologies to preserve permafrost are also being used.[43]
New Brunswick	The New Brunswick Department of Transportation rebuilt and raised a bridge on the main road into Pointe-du-Chêne to accommodate future sea level rise.[44]
Quebec	The Quebec Ministry of Transportation has oversized the diameter of culverts by 10% to help manage heavy precipitation events.[45] The Quebec Ministry of Transportation has introduced a thermal monitoring program for 13 airport runways in Nunavik that are built on land sensitive to permafrost thaw.[46]

[40] Lemmen, D.S., Warren, F.J., James, T.S. and Mercer Clarke, C.S.L. editors, 2016, Canada's Marine Coasts in a Changing Climate; Government of Canada, Ottawa, ON.
[41] Palko, K., 2017, Synthesis. In K. Palko and D.S. Lemmen (Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 12-25). Ottawa, ON: Government of Canada.
[42] Lemmen, D.S., Warren, F.J., James, T.S. and Mercer Clarke, C.S.L. editors, 2016, Canada's Marine Coasts in a Changing Climate; Government of Canada, Ottawa, ON.
[43] Lemmen, D.S., Warren, F.J., James, T.S. and Mercer Clarke, C.S.L. editors, 2016, Canada's Marine Coasts in a Changing Climate; Government of Canada, Ottawa, ON.
[44] Palko, K., 2017, Synthesis. In K. Palko and D.S. Lemmen (Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 12-25). Ottawa, ON: Government of Canada.
[45] Palko, K., 2017, Synthesis. In K. Palko and D.S. Lemmen (Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 12-25). Ottawa, ON: Government of Canada.
[46] Palko, K., 2017, Synthesis. In K. Palko and D.S. Lemmen (Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 12-25). Ottawa, ON: Government of Canada.

Investment in Climate Change Adaptation

This chapter presents the results of an examination of the cost of adaptation in Canada. The objective was to generate a credible estimate of the level of investment that government should be making in municipal infrastructure and other adaptation measures at the local level to reduce the cost of climate change impacts in Canada.

As outlined above, numerous studies confirm that investments in adaptation and risk mitigation projects provide a payback in abated future disaster and climate change related costs.[47] However, despite the importance of adaptation as a strategy to address climate impacts, and the evidence of significant cost avoidance, a limited number of studies have quantified the cost of pursuing adaptation measures. Those that have been completed are mostly at a global scale, such as the 2010 World Bank study which estimated the global annual cost of adaptation at between $70 billion and $100 billion up to 2050 (in 2005 dollars). Following a similar methodology, annual adaptation costs have been estimated to be approximately $40 billion in Asia and the Pacific over the period 2010-2050.[48] The United Nations estimates that industrialized countries would have to spend $22-105 billion annually by 2030 on adaptation to climate-proof infrastructure. Similarly, a study for Europe estimated the cost of climate-proofing new infrastructure at $4.6-58 billion per year.[50]

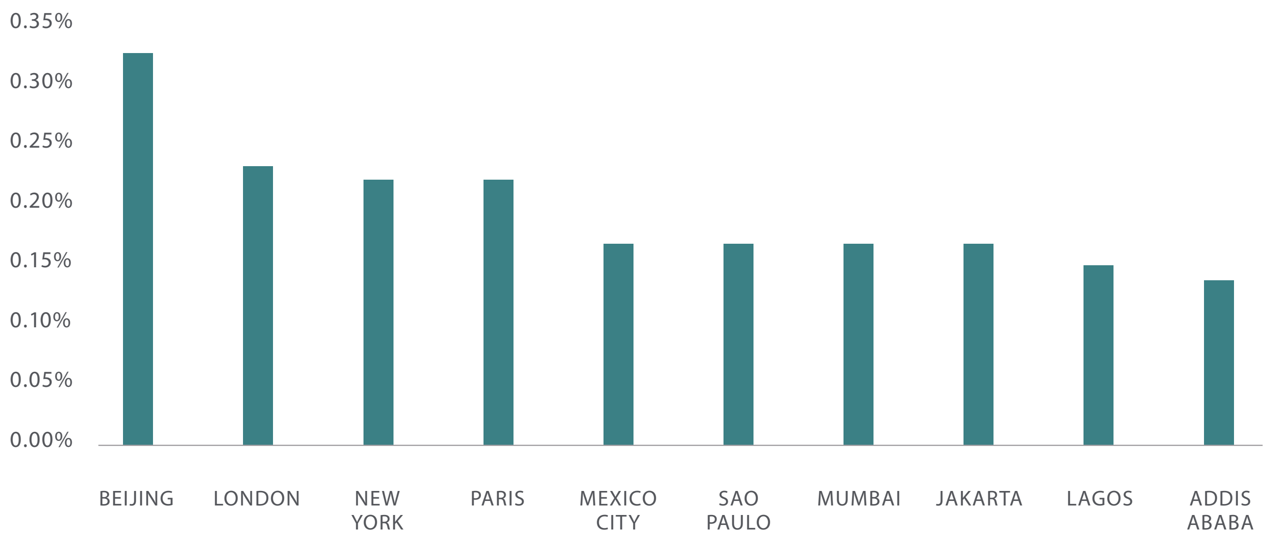
Estimates at a national or local scale are also scarce. Table 6 demonstrates actual public and private expenditures on climate adaptation for three major cities. To put the estimates from the table below into perspective, a study on international resilience investment suggests governments need to be investing 0.66-1.25% of GDP in adaptation measures to minimize the worst impacts of extreme weather events.[51] Figure 3 presents climate adaptation as a percentage of GDP for a select number of countries, demonstrating the range of investment from a high of approximately 0.325% in Beijing to a low of 0.14% in Addis Ababa.

TABLE 6. PUBLIC AND PRIVATE INVESTMENT IN ADAPTATION[52]

CITY	SPENDING 2014/2015	SPENDING AS A % OF GDP	PER CAPITA SPENDING
New York, USA	$2,779 million	0.22%	$270
London England, UK	$1,696 million	0.23%	$167
Paris, France	$1,543 million	0.22%	$563

[47] Martinez-Diaz, L., 2018, Investing in resilience today to prepare for tomorrow's climate change. Bulletin of the Atomic Scientists, 74:22, pp. 66-72.
[48] Adaptation to Climate Change Team, 2015, Paying for Urban Infrastructure Adaptation in Canada: An Analysis of Existing and Potential Economic Instruments for Local Governments, Simon Fraser University.
[49] Georgeson L. et. al., 2016, Adaptation responses to climate change differ between global megacities. Nature Climate Change volume 6, pages 584–588 (2016). Retrieved from: https://www.nature.com/articles/nclimate2944
[50] Springmann, 2012
[51] Martinez-Diaz, L., 2018, Investing in resilience today to prepare for tomorrow's climate change. Bulletin of the Atomic Scientists, 74:22, pp. 66-72.
[52] Martinez-Diaz, L., 2018, Investing in resilience today to prepare for tomorrow's climate change. Bulletin of the Atomic Scientists, 74:22, pp. 66-72.

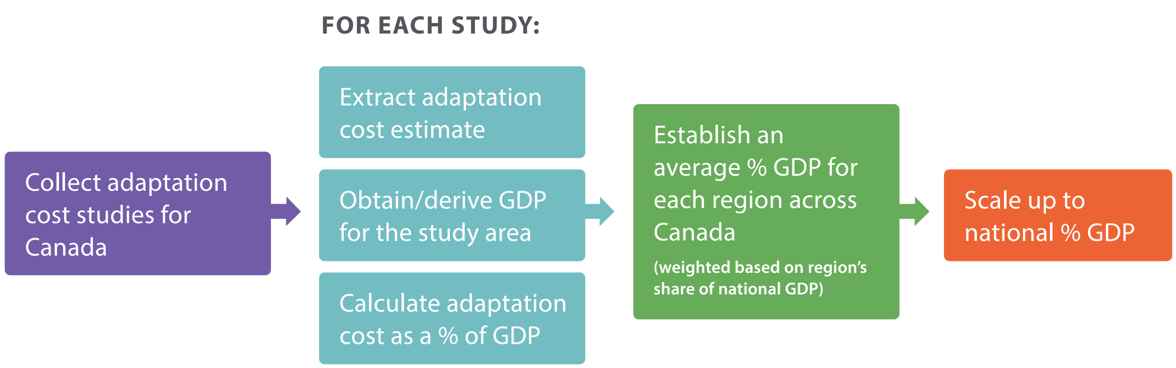
FIGURE 3. CLIMATE ADAPTATION SPENDING AS A PERCENTAGE OF CITY GDP, 2014/2015[53]



4.1 RESEARCH APPROACH

Given the limited number of existing national level assessments of the investment needed for climate change adaptation measures, and the limited amount of Canadian data to work with, it was necessary to develop a methodology that would be comparable to existing estimates but still reflect the unique experience in Canada and work with the various data available. Climate change adaptation costs for a small town on the east coast will be very different compared to the costs for the City of Saskatoon, for example. Figure 4 depicts the overall approach that was used to complete the assessment of climate adaptation costs in Canada and the level of investment needed at a national scale.

FIGURE 4. OVERVIEW OF APPROACH FOR ASSESSMENT OF CLIMATE ADAPTATION COSTS



[53] Georgeson L. et. al. (2016). Adaptation responses to climate change differ between global megacities. Nature Climate Change volume 6, pages 584–588 (2016). Retrieved from: https://www.nature.com/articles/nclimate2944

4.1.1 COLLECT ADAPTATION COST STUDIES

The analysis of adaptation costs for Canada began with collecting studies that have quantified the cost of adaptation at the community level from across the country. These studies are distinct from those that describe actual spending (as this is not necessarily a reflection of what should be spent but rather what has been spent) and from studies that quantify the cost of climate impacts (which are known to exceed the cost of adaptation). The objective was to obtain studies that describe the cost of adaptation from a range of locations (East, West, Central and Northern Canada), population sizes and climate risks. The studies were collected and reviewed and adaptation cost estimates extracted.

4.1.2 EXTRACT ADAPTATION COST ESTIMATES

Adaptation cost estimates and details pertaining to their derivation were extracted from the climate adaptation studies and entered into a database. The database contains the following details extracted from each study:

- Location
- Province/Territory
- Adaptation Measures
- Infrastructure Type
- Climate Risk Applicable to Adaptation Measures
- Cost
- Study Timeframe
- Study Year
- Discount Rate
- Reference Details

Information added to the database for each of the studies includes:

- Population
- Lifespan of Infrastructure
- Gross Domestic Product

The cost estimates for each study needed to be adjusted to allow for tallying across actions and communities. To do this, several steps were taken. First, it was necessary to establish a planning horizon. This is the time period over which total adaptation costs would be estimated. For this project a planning horizon of 50 years was applied. The timeframe, combined with the lifespan of the infrastructure, determines the total cost of the adaptation measure for a community. Costs associated with infrastructure with shorter lifespans will recur numerous times over the planning horizon, while costs associated with infrastructure with longer lifespans will occur less times over the planning horizon. All cost estimates were then translated into annual cost values. This was done by taking the cost estimate and dividing it by the number of years the associated action is implemented over (a time horizon specified in the studies or assumed to be 1). Present values were then established (at a 2% discount rate) and estimated over the 50-year planning horizon taking the frequency of the cost into account. Final cost estimates were converted to a common year (2019) to facilitate comparisons across studies. Cost estimates that could not be converted to total cost values, for example studies with costs per kilometre of road or per bridge, were removed from the database. Studies that covered geographic regions for which a GDP estimate could not be established, for example studies that did not specify specific communities, were removed from the database. It should be noted that the climate change scenario (i.e., 1.5 or 2 degree warming) was not standardized across studies given the limited data available.

4.1.3 OBTAIN/DERIVE GDP FOR THE STUDY LOCATIONS

For the study locations corresponding to the adaptation cost estimates, an estimate of GDP was then obtained or derived. If the study area was a CMA (census metropolitan area), the GDP estimate corresponding to the study location was obtained from Statistics Canada. If the study area was something other than a CMA, a GDP estimate was derived. Appendix C describes the approach employed to derive GDP estimates for study locations.

4.1.4 CALCULATE ADAPTATION COST AS A PERCENT OF GDP

The adaptation cost estimates (4.1.2 above) for each community were then calculated as a percent of GDP (4.1.3 above) for the same community.

4.1.5 ESTABLISH A RANGE OF GDP PERCENTAGES

The percentage of GDP was then tallied across all of the communities to estimate an average adaptation cost as a percentage of GDP. Percentages were also examined by region (West, East, North, Central Canada), infrastructure type, climate risk and population.

4.2 RESULTS

This section of the report presents the results of the assessment. Details pertaining to the climate adaptation cost database are provided along with the range of adaptation costs as a percentage of GDP that were derived.

4.2.1 ADAPTATION COST DATABASE

The final database employed for the study contains 414 adaptation cost estimates for 34 different locations across the country. Table 7 shows the number of communities represented in the database by province. There are more communities in Alberta than other locations because numerous communities in Alberta have completed the “Climate Resilience Express” program. The Climate Resilience Express program is a streamlined process for developing climate resilience action plans for smaller communities. Through this program, communities identify climate risks and quantify relevant adaptation costs.[54] No such program was identified for other jurisdictions, with the exception of the nationally available BARC program through ICLEI Canada (See section 3.4).

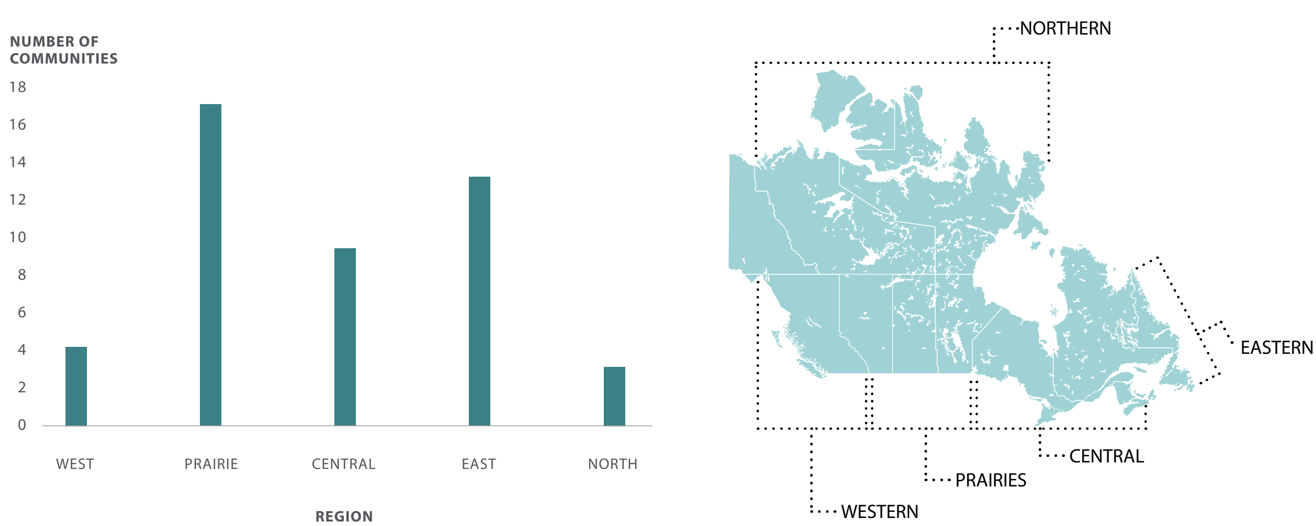
[54] http://allonesky.ca/climate-resilience-express-project/

TABLE 7. COMMUNITIES REPRESENTED IN THE CLIMATE ADAPTATION COST DATABASE

PROVINCE	NUMBER OF COMMUNITIES REPRESENTED
British Columbia	4
Alberta	13
Saskatchewan	1
Manitoba	3
Ontario	4
Quebec	4
Ontario and Quebec	1
Nova Scotia	4
New Brunswick	4
Nova Scotia and New Brunswick	1
Newfoundland Labrador	2
Prince Edward Island	2
Yukon Territory	1
Northwest Territories	2

Figure 5 demonstrates the distribution of the communities by region. The database contains cost estimates for 17 communities in Alberta, Saskatchewan and Manitoba (Prairie region) with the majority of those studies for Alberta communities (13 of the 17 communities). Thirteen communities are from eastern provinces (Nova Scotia, New Brunswick, Newfoundland & Labrador, and Prince Edward Island), 9 are from central provinces (Ontario and Quebec), and the remainder are from western provinces (British Columbia) and northern territories (Northwest Territory, Yukon). No studies were identified from Nunavut.

FIGURE 5. NUMBER OF COMMUNITIES IN THE CLIMATE ADAPTATION COST DATABASE BY REGION



Fifteen categories of infrastructure are represented in the database. Table 8 demonstrates the number of cost estimates in the database by infrastructure type. Roads and green infrastructure are well represented in the database at 33 and 28 cost estimates, respectively. A large number of cost estimates were identified for dikes (25), water treatment (21) and technology and equipment (21).

TABLE 8. COST ESTIMATES BY INFRASTRUCTURE TYPE

INFRASTRUCTURE TYPE	NUMBER OF COST ESTIMATES
Bridges	1
Buildings	13
Combined	12
Dikes	25
Green Infrastructure	28
Maintenance	12
Other	3
Roads	33
Seismic	2
Sewer	10
Technology & Equipment	21
Utilities	4
Water Treatment	21

The table above does not include the administrative cost estimates that were identified and included in the database. Two hundred and twenty-nine administrative cost estimates are included in the database. The majority of the administrative costs are for communities that have participated in Alberta's Climate Resilience Express program. Appendix D lists the specific administrative measures that are included in the database for all locations, demonstrating how they relate to public infrastructure.

Nine climate risks are captured in the database. Table 9 demonstrates the distribution of the cost estimates across climate risks. As is evident, flood is the most well represented climate risk in the database.

TABLE 9. COST ESTIMATES BY CLIMATE RISK

CLIMATE RISK	NUMBER OF COST ESTIMATES
Combined	74
Drought	70
Erosion	15
Flood	138
Heatwave	4
Other*	6
Permafrost Melt	11
Storm	45
Wildfire	51

*Shifting agriculture growing season due to changing temperature patterns

Table 10 demonstrates the distribution of cost estimates by climate risk and infrastructure type (excluding administration). As is noted above, flood risk is associated with the greatest number of cost estimates. It is also associated with the widest range of infrastructure types.

TABLE 10. COST ESTIMATES BY CLIMATE RISK AND INFRASTRUCTURE TYPE

CLIMATE RISK	INFRASTRUCTURE TYPE	NUMBER OF COST ESTIMATES
Combined	Buildings	1
	Combined	2
	Green Infrastructure	2
	Maintenance	3
	Roads	2
	Technology & Equipment	4
	Utilities	1
Drought	Dikes	2
	Green Infrastructure	5
	Other	2
	Technology & Equipment	2
	Water Treatment	2
Erosion	Bridges	1
	Dikes	4
	Green Infrastructure	4
	Maintenance	2
	Roads	4
Flood	Buildings	6
	Combined	6
	Dikes	18
	Green Infrastructure	13
	Maintenance	7
	Other	1
	Roads	14
	Seismic	2
	Sewer	10
	Technology & Equipment	5
	Water Treatment	19
Heatwave	Other	6
	Admin	6
	Permafrost Melt	11
	Buildings	2
	Roads	9
Storm	Buildings	4
	Dikes	1
	Green Infrastructure	2
	Roads	3
	Technology & Equipment	4
	Utilities	3
Wildfire	Combined	4
	Green Infrastructure	2
	Roads	1
	Technology & Equipment	6

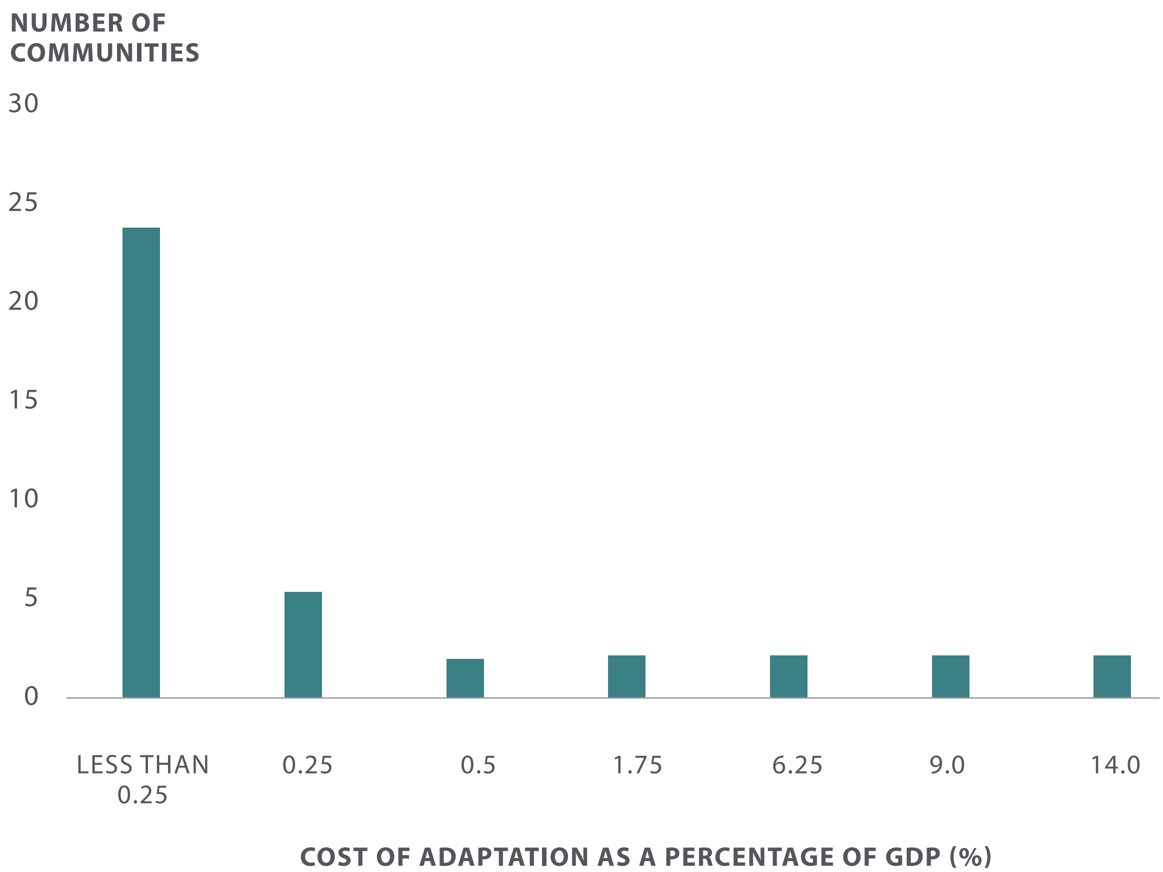
4.2.2 ADAPTATION COST AS A PERCENTAGE OF GDP

As is noted in Section 4.1, after the adaptation cost database was cleaned and adjusted as needed, the cost estimates were summed by community and the adaptation cost as a percentage of GDP for each community was established. The percentages are presented in this section of the report, assuming a 50-year planning horizon and a 2% discount rate. The following sections provide a summary of how the adaptation costs as a percentage of GDP differs according to location, infrastructure type, climate risk, and population. The final section provides the methodology and results of scaling up the regional results to estimate a national level of investment in adaptation as a percentage of GDP.

4.2.2.1 ADAPTATION COST AS A PERCENTAGE OF GDP FOR ALL STUDIES

Figure 6 shows the distribution of the adaptation cost as a percentage of GDP for all studies. The majority of the results are less than 0.5% of GDP but range from a low of 0.00005% to a high of 14%. The average of all results rounds to 1.0% from 0.99698%. The median value is 0.06%. The three highest percentages are from small coastal towns on the east coast of Canada (the fourth highest percentage is from a coastal area in NB and NS). These communities have relatively small GDPs and high adaptation costs given their vulnerability to coastal climate risks.

FIGURE 6. NUMBER OF COMMUNITY COST ESTIMATES BY COST OF ADAPTATION AS A PERCENTAGE OF GDP



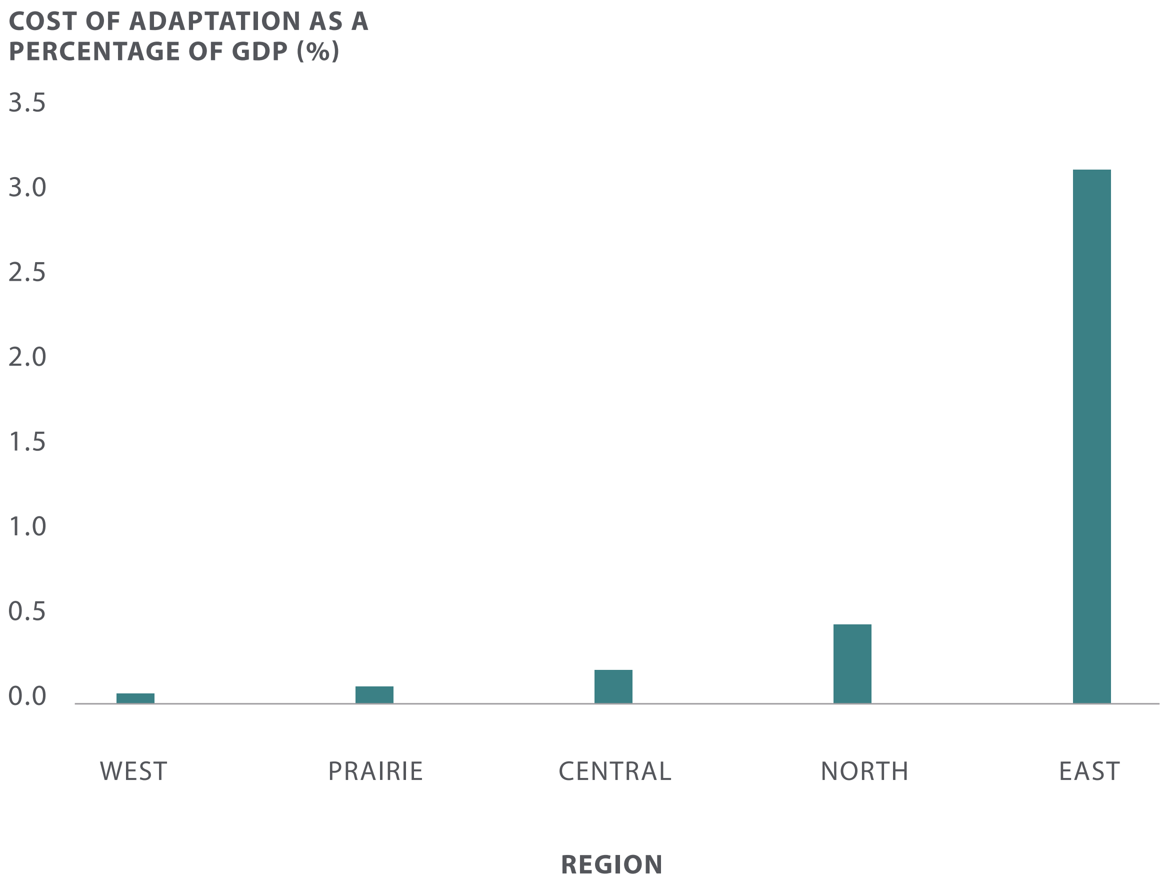
Given the number of estimates in the database that relate to administrative costs (i.e., 229 cost estimates for administrative actions relative to 185 cost estimates for all other infrastructure types), a percentage of GDP was derived excluding the administrative cost estimates from the analysis. Doing so resulted in the elimination of two communities (i.e., there were two communities for which the only infrastructure type captured in the adaptation cost estimates was administration; other communities had administration costs but also costs for other infrastructure types). The average adaptation cost as a percentage of GDP for the remaining communities (excluding administrative costs) is 1.05%, somewhat higher than the average when administrative costs are included.

4.2.2.2 ADAPTATION COST BY LOCATION

Figure 7 presents adaptation cost as a percentage of GDP by region. The Central region contains estimates from Ontario and Quebec, the West region contains estimates from British Columbia, the Prairie region is comprised of estimates from Alberta, Manitoba and Saskatchewan, the East region reflects estimates from Nova Scotia, New Brunswick, Newfoundland & Labrador and Prince Edward Island, while the North region is comprised of studies from Yukon and Northwest Territory. No studies were identified from Nunavut.

The average percentage of GDP for the East region is 3.20%. The North region has the next highest average at 0.37%. This is followed by the Central region, where the average percentage is 0.12%, the Prairie region which has an average percentage of 0.06%, and the West region, which has an average percentage of 0.015%. While the higher percentage observed for the East region in Figure 7 may appear as an outlier relative to the other regions, this may not be the case. On the contrary, given the relatively small dataset employed in this analysis, the higher percentages observed for eastern communities might be representative of a larger population of communities in that region (i.e., if more data points were available, the gap between the upper and lower averages may be filled). The four highest percentages in the database are from coastal communities in eastern provinces (two from Newfoundland & Labrador, one from New Brunswick and Nova Scotia combined and one from Nova Scotia). These communities have relatively low GDP and relatively high risk given that they are located on the coast. Thus, the percentages observed for these communities could very well be representative of numerous small coastal communities in eastern Canada. Upon investigation, it was revealed that 20 communities in the eastern region match the profile of the communities in the database with these high percentages. These communities are located on the coast and have populations of 6,000 or less (see Appendix E for a list of comparable communities and a description of how they were identified).

FIGURE 7. ADAPTATION COST AS A PERCENTAGE OF GDP BY REGION



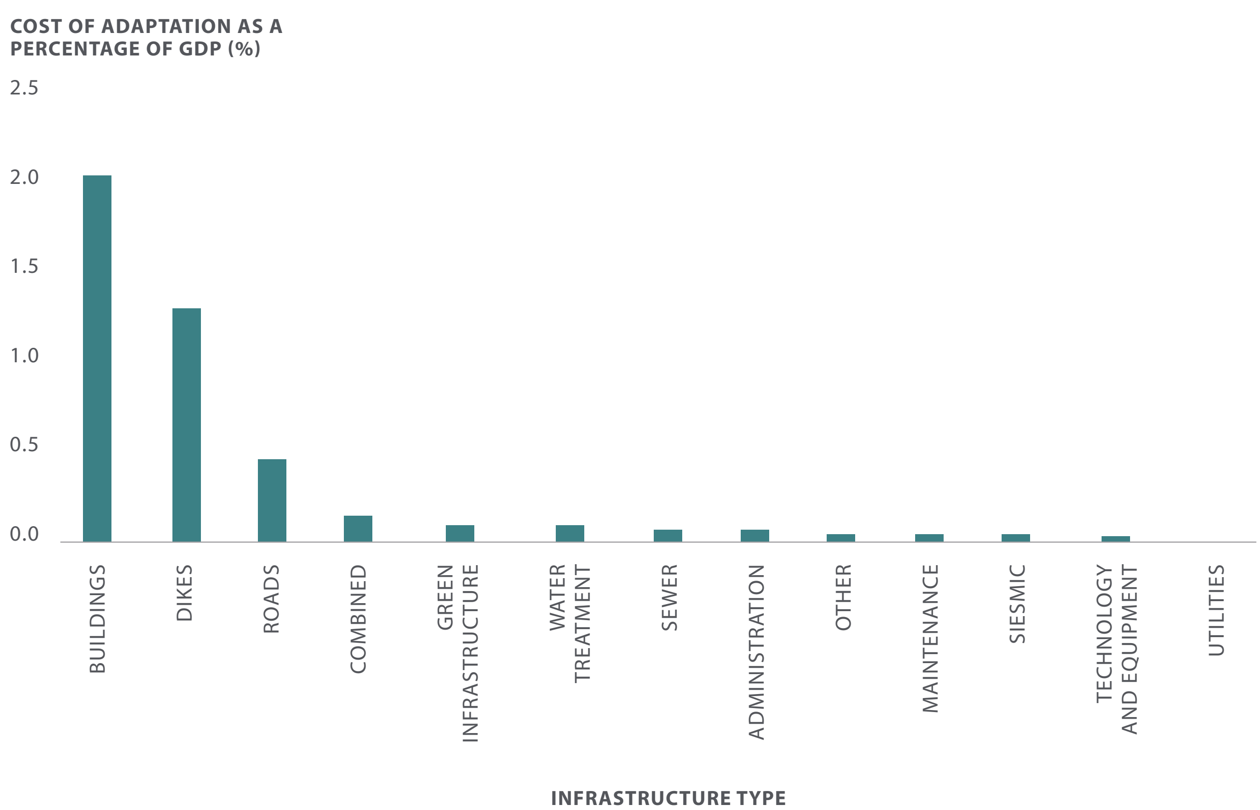
As was noted earlier, more cost estimates were obtained for the province of Alberta than other provinces and territories due to the number of communities that have participated in the Climate Resilience Express program. Given this, it was deemed appropriate to derive an Alberta-only climate adaptation cost as a percentage of GDP. To that end, cost estimates from 13 Alberta communities were used to derive an average percentage for the province of Alberta. Assuming a 50-year planning horizon and a 2% discount rate (as was assumed for all other results presented in this report), the percentage for just Alberta is 0.06%. The percentages for Alberta communities range from a low of 0.00047% to a high of 0.16%. The majority of the percentages fall between 0.03% and 0.08%.

4.2.2.3 ADAPTATION COST BY INFRASTRUCTURE

Figure 8 shows adaptation as a percent of GDP by infrastructure type. The relatively higher estimates for buildings, dikes and roads are visible in the figure below. The average percentage for buildings is 2.01%, for dikes is 1.18% and for roads is 0.47%. The average percentage for green infrastructure and water treatment is 0.05%; for administration it is 0.03%.

Grouping the infrastructure types as grey, green and soft reveals the following information. Grey infrastructure has the highest average percentage of GDP at 0.75%. For green infrastructure it is 0.05% and for soft infrastructure (or administrative actions) it is 0.03%. Adaptation costs as a percentage of GDP by climate risk are presented in Figure 9. The figure demonstrates the relatively higher cost for floods.

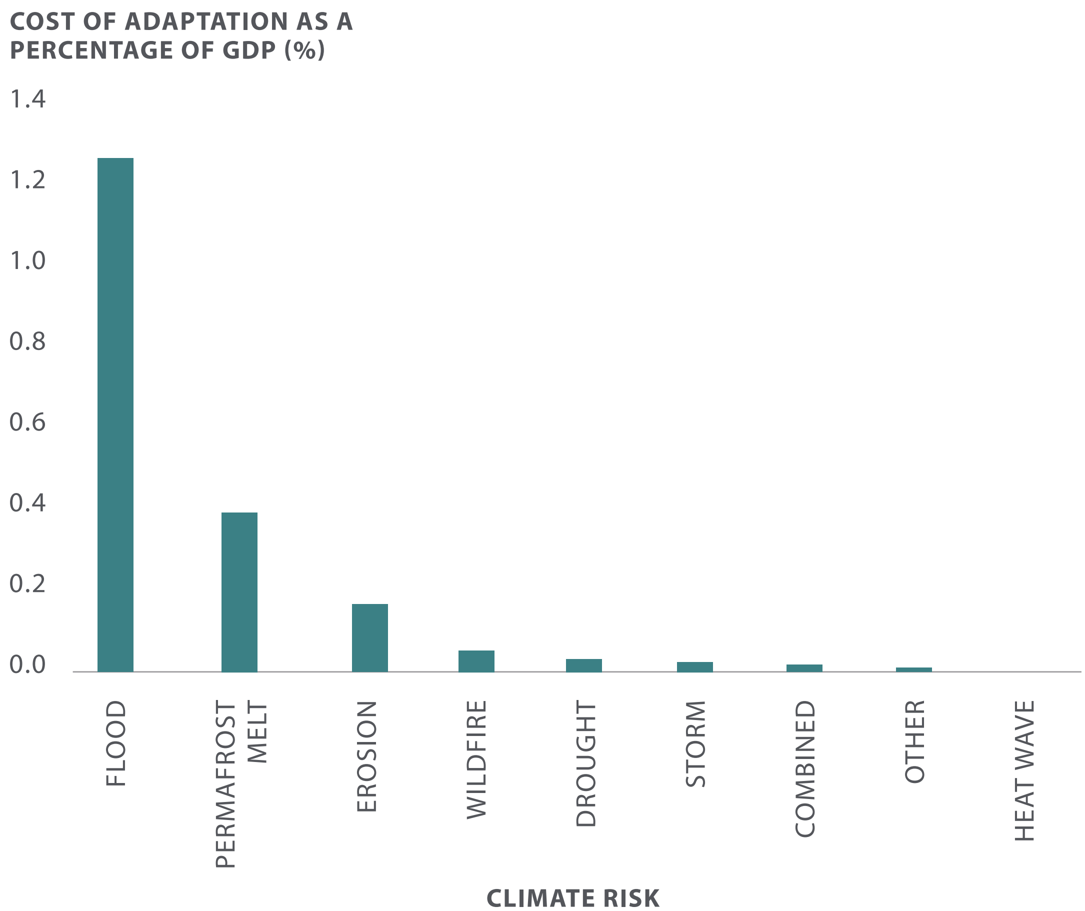
FIGURE 8. ADAPTATION COST AS A PERCENTAGE GDP BY INFRASTRUCTURE TYPE



4.2.2.4 ADAPTATION COST BY CLIMATE RISK

Adaptation costs as a percentage of GDP by climate risk are presented in Figure 9. The figure demonstrates the relatively higher cost for floods. The average percentage of GDP for flooding is 1.25%, for permafrost is 0.37% and for erosion is 0.12%.

FIGURE 9. ADAPTATION COST AS A PERCENTAGE OF GDP BY CLIMATE RISK



4.2.2.5 ADAPTATION COST BY POPULATION

Figure 10 shows the number of cost estimates within the database by population size. As is clear in the figure, the majority of the cost estimates are for relatively smaller communities (less than 190,000). Figure 11 demonstrates how the cost estimates translate into average percentages of GDP across a range of community population thresholds. The higher percentages are associated with lower population communities (less than 5,600). Such communities have relatively lower GDP values but potentially significant adaptation costs, depending on their location and climate risks. For example, communities with low GDP located on the east coast and prone to flood and erosion impacts, have the highest adaptation costs as a percentage of GDP. The average percentage of GDP for communities with populations under 5,600 is 2.8%. For communities with populations of more than 5,600 but less than 71,900 the average percentage is 0.2% and for communities with populations greater than 71,900 it is 0.07%.

FIGURE 10. NUMBER OF COMMUNITY COST ESTIMATES BY POPULATION

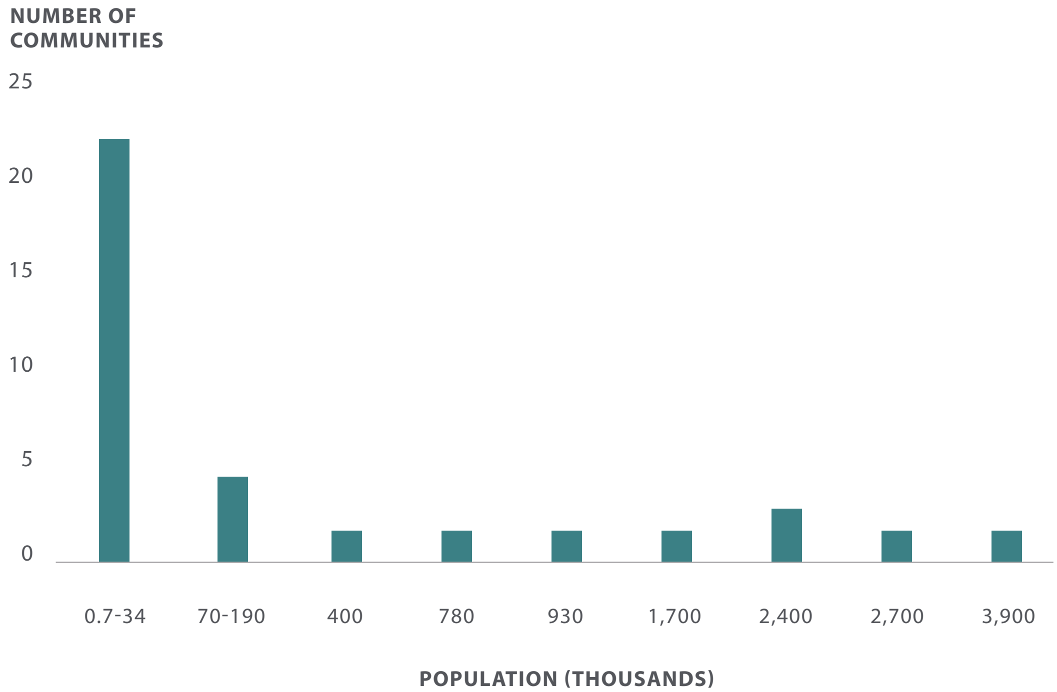
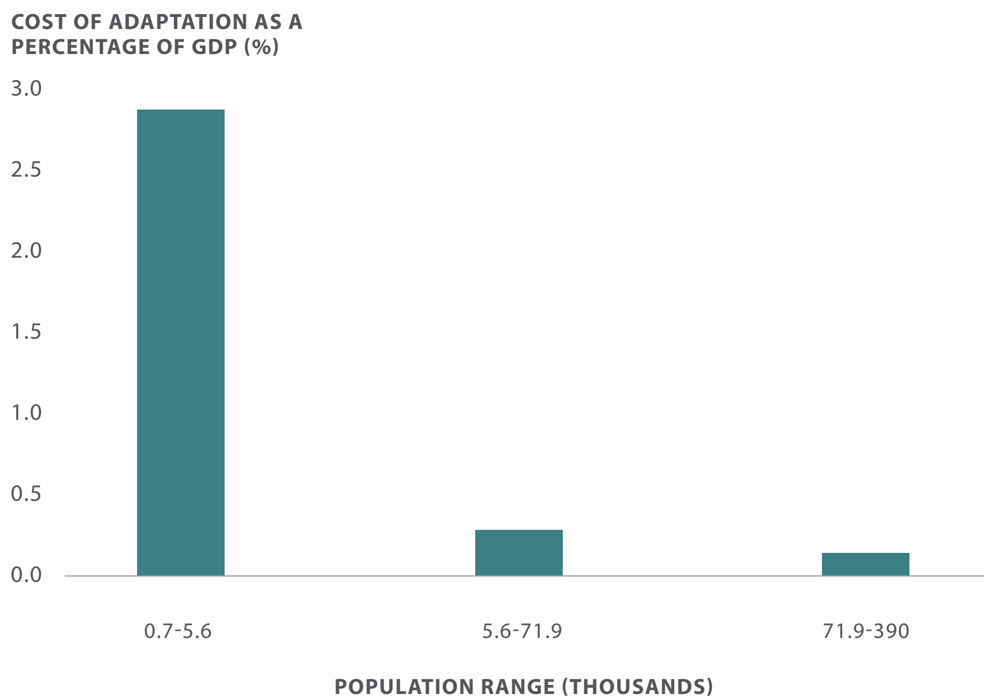


FIGURE 11. ADAPTATION COST AS A PERCENTAGE OF GDP BY POPULATION



4.2.2.6 NATIONAL LEVEL OF INVESTMENT IN ADAPTATION

To derive dollar estimates for the amount of required expenditure on a regional basis, GDP values were calculated for the respective regions and the % GDP by region applied to them. (Table 11). These regional results were then combined to give an estimate of the annual national level of investment in adaptation at the local level. The analysis determined that an average annual investment in municipal infrastructure adaptation measures of $5.3 billion is needed to adapt to climate change. In national terms, this represents an annual expenditure of 0.26% of GDP. This estimate represents the total cost of the actions that need to be taken at the municipal level and would typically be cost-shared between each order of government.

TABLE 11. ESTIMATE OF THE ANNUAL NATIONAL LEVEL OF INVESTMENT IN ADAPTATION AT THE LOCAL LEVEL

REGION	% NATIONAL GDP	REGIONAL GDP ($ BILLIONS)	AVG REGIONAL COST OF ADAPTATION : GDP (%)	AVG REGIONAL COST OF ADAPTATION : GDP ($ BILLION)
East	5.55	$111.6	3.2	$3.6
North	0.50	$10.1	0.37	$0.04
ON/QC	58.15	$1,168.82	0.12	$1.4
Prairie	22.57	$453.7	0.06	$0.3
West	13.20	$265.3	0.015	$0.04
TOTAL				**$5.3**

Conclusion

Trends in climate adaptation in Canada in the past five-to-ten years have progressed from research, to expanded engagement, to more and more examples of implementation. Communities and governments have moved past awareness and are increasingly pursuing specific measures to reduce the impact of climate change.[55] Today, in Canada, there are examples of adaptation measures at all levels of government, within industry groups and individual companies.[56] Despite the growing trend in adaptation measures in Canada, few studies have quantified the cost of adaptation and such studies are particularly lacking at local and municipal levels.[57]

The objective of this study was to establish a credible estimate of government spending on climate change adaptation measures to reduce the cost of climate change in Canada. Studies that have quantified the cost of adaptation from across the country were used to estimate an average investment in adaptation as a percentage of GDP and to examine whether such data varies by location, population, infrastructure type and climate risk. The analysis revealed an average percentage, weighted by regional variations, across all studies, populations, communities, locations, climate risks and infrastructure types of 0.26% of national GDP or $5.3 billion annually. This figure represents adaptation investment in local public infrastructure only that would be cost-shared between the three levels of government.

Flood, erosion and permafrost are associated with the highest adaptation costs at 1.25%, 0.12% and 0.37% of GDP, respectively. These are the climate risks requiring the greatest investment in adaptation. Grouping the infrastructure types as grey, green and soft reveals that grey infrastructure has the highest average adaptation cost as a percentage of GDP at 0.75%. The percentage for green infrastructure is 0.05% and that for soft infrastructure (or administrative actions) is 0.03%, indicating relatively lower costs for these adaptation measures. From a regional perspective, the East, at 3.20%, and the North, at 0.37%, are characterized by relatively higher costs as a percentage of GDP, indicating that these regions are most in need of adaptation spending to protect against climate risks.

When considering the results presented above, it is important to keep in mind the number of cost estimates employed in the analysis. As noted in section 4, the database contains 414 cost estimates from 34 locations in Canada. This is a relatively small sample size given the number of communities of varying sizes and exposure to climate risks across the country. Particular gaps in the database exist for mid-sized cities and communities in British Columbia. There are more cost estimates for Alberta than any other province with a total of 13 communities represented in the database. While this may be, relatively speaking, an overrepresentation of Alberta communities, the key consideration is the degree to which the Alberta communities are representative, in terms of size, GDP and climate risks, of a larger population of similar communities across the country. Given the reliance on Alberta-specific data, community profiling was undertaken to examine the degree to which the Alberta communities are representative of a larger sample of communities across the country. Upon investigation, 134 such communities were identified. These communities, from Saskatchewan, Ontario, Manitoba and Quebec, face a similar climate risk profile, are not coastal communities, and have similar populations and land areas. Other data points that may appear as outliers, such as the percentages for the small coastal communities in eastern Canada, warrant the same consideration (see Appendix E for the approach employed for community profiling as well as communities identified as similar in nature to the Alberta and east coast communities contained in the database).

[55] Warren, F.J. and Lemmen, D.S., editors, 2014, Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON.
[56] Warren, F.J. and Lemmen, D.S., editors, 2014, Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON.
[57] Adaptation to Climate Change Team, 2015, Paying for Urban Infrastructure Adaptation in Canada: An Analysis of Existing and Potential Economic Instruments for Local Governments, Simon Fraser University.

The results presented here rely on previous studies that have quantified the cost of adaptation for communities in Canada. There is an underlying assumption that the studies have targeted the major climate risks that each community is exposed to. To the extent that the cost estimates represent a portion of the total climate risk for any given community, the percentages will underestimate adaptation spending. Related to this point, it is obvious that there is a lack of studies that have quantified adaptation costs for communities in Canada. Results from FCM's Municipalities for Climate Innovation Program (funded by Infrastructure Canada), point to an ongoing need to continue to build municipal capacity to assess climate risk and identify the optimal responses. As more communities conduct climate risk and vulnerability assessments and identify the cost of action, future research can shed more light of the cost of climate impacts to help build the case for continued and expanded investment in climate adaptation in this country. As well, given the size of the estimated investment needed at the local level, the role of the private sector and how private finance can support enhanced community resilience should also be considered in future research and analysis.

This research is the first attempt to quantify what Canadian governments need to be spending on local disaster mitigation and adaptation projects to reduce the impacts of climate change. In releasing this report, IBC and FCM hope to contribute to the growing body of knowledge on climate change adaptation in the Canadian context. The cost of climate change adaptation will continue to be better understood as more data on adaptation investments becomes available and additional research along these lines is undertaken.

Climate Impacts to Public Infrastructure

TABLE A1. CLIMATE CHANGE AND INFRASTRUCTURE IMPACTS: LAND TRANSPORTATION[58]

CLIMATE HAZARD AND/OR WEATHERING PROCESS LIKELY AFFECTED BY A CHANGING CLIMATE	POTENTIAL INFRASTRUCTURE IMPACTS
Permafrost degradation and greater frequency of freeze-thaw cycles in winter months	• Soil instability, ground movement and slope instability • Triggered instability of embarkments and pavement structures (ditches, culverts, drains, street hardware, bridges, tunnels) • Increased frequency, duration and severity of thermal cracking, rutting, frost heave and thaw weakening
Hotter, drier summers	• Pavement softening • Reduction in the maximum loads that can be safely transported • Asphalt-covered surfaces are more susceptible to damage during heat waves • Increase in flushing or bleeding of older pavement • Shortened ice road seasons by several weeks • Change in the timing and duration of seasonal load restrictions and winter weight premiums • Increased challenges in pavement construction process • Shortened life expectancy of highways, roads and rail • Drier conditions affecting the life cycle of bridges and culverts • Increased flow of streams and rivers, which increases need to replace ice bridges • Augmentation of urban heat island effect
Milder winters	• Longer construction season, fewer pothole repairs • Less frost damage for southern roads • Decreased damage from fewer freeze-thaw cycles • Changes to maintenance schedules
Sea-level rising, increased frequency of storm surges, higher tides and flooding	• Capacity of culverts and storm sewer systems are more frequently exceeded; road damage, bridge washouts, underpass and basement flooding, increased repair bills and insurance costs • Causeways, bridges and low-lying roads have a high risk of being inundated or damaged • Coastal roads may be required to be moved or be rebuilt at higher elevation to avoid or reduce flooding

[58] Boyle J. et. al., 2013, Climate Change Adaption and Canadian Infrastructure. The International Institute for Sustainable Development. Winnipeg, Manitoba.

TABLE A2. CLIMATE CHANGE AND INFRASTRUCTURE IMPACTS: BUILDINGS[59]

CLIMATE HAZARD AND/OR WEATHERING PROCESS LIKELY AFFECTED BY A CHANGING CLIMATE	INFRASTRUCTURE IMPACTS
Permafrost degradation	• Soil subsidence and buckling can damage a property's foundation infrastructure • Loss of strength in buildings, which can cause them to become uninhabitable • Reduced strength and reliability of containment structures and other physical infrastructure
Hotter, drier summers and heat waves	• Building damage has sometimes been observed when clay soils dry out • Forest fires can damage entire homes and businesses • Premature weathering • Increased indoor air temperature and reliance on cooling systems
Increased precipitation	• Reduced structural integrity of building components through mechanical, chemical and biological degradation • Accelerated deterioration of building facades • Premature weathering of input materials • Increased fractures and spalling in building foundations • Decreased durability of materials • Increased efflorescence and surface leaching concerns • Increased corrosion • Increased mold growth
Increased rainfall, storm surges and higher tides	• Damaged or flooded structures • Slope stability and integrity of engineered berms are also vulnerable to extreme precipitation • Coastal infrastructure inducted • Wharves to be rebuilt, moved or raised to avoid inundation • Increased risk of basement and localized flooding • Increased corrosion in metals or deterioration in concrete
Hurricanes, tornadoes, hail, windstorms and ice storms	• Property destruction • Damaged building infrastructure • Reduction of design safety margins • Reduced service life and functionality of components and systems • Increased risk for catastrophic failure • Increased repair, maintenance, reserve fund contingencies and energy costs

[59] Boyle J. et. al., 2013, Climate Change Adaption and Canadian Infrastructure. The International Institute for Sustainable Development. Winnipeg, Manitoba.

TABLE A3. CLIMATE CHANGE AND INFRASTRUCTURE IMPACTS: WATER INFRASTRUCTURE[60]

CLIMATE HAZARD AND/OR WEATHERING PROCESS LIKELY AFFECTED BY A CHANGING CLIMATE	INFRASTRUCTURE IMPACTS
Drought	• Increased water demands and pressure on infrastructure • Water apportion issues • Loss of potable water • Increased water quality problems • Increased risk of flooding • Dam failures
Permafrost degradation	• Rupture of drinking water lines • Rupture of water storage tanks • Increased turbidity and sediment loads in drinking water
Rising sea level	• Saltwater intrusion in groundwater aquifers
Flooding	• Water-borne health effects from increased flooding • Volatilization of toxic chemicals • Summer taste/odour problems in municipal water supply

TABLE A4. CLIMATE CHANGE AND INFRASTRUCTURE IMPACTS: MARINE INFRASTRUCTURE[61]

CLIMATE HAZARD AND/OR WEATHERING PROCESS LIKELY AFFECTED BY A CHANGING CLIMATE	INFRASTRUCTURE IMPACTS
Less ice cover; remaining ice is more mobile and wave action is more intense	• Marine infrastructure becomes more vulnerable to storm surges and extreme weather • Accelerated erosion and sedimentation of marine infrastructure • Affects the future design and operation of near shore and shore infrastructures • Increased construction of marine infrastructure, expansion of ports, associated with higher and less seasonal marine traffic as Arctic Sea melt continues
Flooding, coastal erosion, storm surges	• More extensive coastal inundation; flooding of marine infrastructure • Increased force exerted on docks • Saltwater intrusion into freshwater aquifers • Coastal erosion makes coastal infrastructure unstable • Land-based installations, such as oil storage reservoirs or storage facilities must be protected with seawalls to avoid damage
Flooding	• Cargo ships unable to access marine infrastructure during low tide

[60] Boyle J. et. al., 2013, Climate Change Adaption and Canadian Infrastructure. The International Institute for Sustainable Development. Winnipeg, Manitoba.
[61] Boyle J. et. al., 2013, Climate Change Adaption and Canadian Infrastructure. The International Institute for Sustainable Development. Winnipeg, Manitoba.

TABLE A5. CLIMATE CHANGE AND INFRASTRUCTURE IMPACTS: WASTEWATER INFRASTRUCTURE[62]

CLIMATE HAZARD AND/OR WEATHERING PROCESS LIKELY AFFECTED BY A CHANGING CLIMATE	INFRASTRUCTURE IMPACTS
Permafrost degradation	• New containment structures in continuous permafrost zone may need to be built • Potential rupture of drinking water and sewage lines, sewage storage tanks • Potential seepage from sewage storage • Failure of frozen-core dams on tailing ponds due to thawing and differential settlement
Hotter, drier summers and heat waves	• Increased demand for water delivery and collection systems
Increase in rainfall	• Stormwater infrastructure more frequently exceeded • Require increased capacity on wastewater treatment facilities • Urban drainage systems could fail, causing problems such as sewer backups and basement flooding
Increased frequency of storm surges and higher tides	• Implications for large urban drainage systems • Potential impact on the strength in wastewater systems • Sinking of land surfaces • Buildings, tankage, housed process equipment affected by flooding • Overtaxing of drainage facilities • Pipeline ruptures

[62] Boyle J. et. al., 2013, Climate Change Adaption and Canadian Infrastructure. The International Institute for Sustainable Development. Winnipeg, Manitoba.

The Cost of Future Climate Change Risks

As the frequency and intensity of extreme weather events increase due to climate change, so too do the impacts and associated costs. The Fraser Basin Council (2016) modelled economic loss projections using the HAZUS model for four major Lower Mainland flood scenarios to inform the Lower Mainland Flood Management Strategy.[63] Scenarios modelled included two coastal flood scenarios (2016 and 2100) and two Fraser River flood scenarios (2016 and 2100). Analysis of total economic loss projections under flood scenarios focused on building-related losses and damage costs for infrastructure and agriculture and lost productivity attributed to interrupted cargo shipments only. The two 2016 flood scenarios were estimated to result in losses of $19.3 billion (coastal flood) and $22.9 billion (Fraser River flood). The flood damages for the 2100 scenarios were estimated to result in losses of $24.7 billion to $32.7 billion. Estimated damage to infrastructure under the four scenarios ranged from $1.4 billion to $5 billion (Table B1). Any one of the four major Lower Mainland flood scenarios analyzed would be expected to trigger the costliest natural disaster in Canadian history to date, creating severe strain on the regional, provincial and national economies.[64]

TABLE B1. TOTAL ECONOMIC LOSS PROJECTIONS UNDER FLOOD SCENARIOS (FRASER BASIN), $ BILLIONS

FLOOD SCENARIO	RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC/ INSTITUTIONAL BUILDINGS	INTERRUPTED CARGO SHIPMENTS	INFRASTRUCTURE	AGRICULTURE	TOTAL
Coastal (2016)	$5.6	$6.3	$1.6	$0.72	$3.6	$1.4	$0.1	**$19.3**
Coastal (2100)	$7.1	$8.6	$2.6	$0.91	$3.6	$1.8	$0.2	**$24.7**
River (2016)	$2.6	$3.8	$1.6	$0.88	$7.7	$4.6	$1.6	**$22.9**
River (2100)	$6.6	$7.6	$2.9	$1.2	$7.7	$5.0	1.6	**$32.7**

Source: Fraser Basin Council. 2016.

An analysis completed by Green Analytics and the Ontario Centre for Climate Impacts and Adaptation Resources for the Insurance Bureau of Canada (2015) modelled the potential costs of climate related extreme weather events on two communities, namely Halifax Regional Municipality (HRM) and Mississauga. The study calculated the expected cost of direct and secondary impacts from asset damage and business interruptions (lost economic output) due to climate-related extreme events assuming no climate adaptation actions are taken. The case study analysis for the HRM focused on the costs of storm surge flooding and extreme wind. The expected annual damage of direct and secondary impacts attributed to climate change by 2040 for storm surge flooding is over $35 million of gross domestic product ($2013) and over $140 million of gross domestic product ($2013) for extreme wind.[65]

[63] Fraser Basin Council. 2016. Lower Mainland Flood Management Strategy, Phase 1 Summary report. May 2016.
[64] Fraser Basin Council. 2016. Lower Mainland Flood Management Strategy, Phase 1 Summary report. May 2016.
[65] Insurance Bureau of Canada. 2015. The Economic Impacts of the Weather Effects of Climate Change on Communities.

The case study analysis for Mississauga focused on the costs of stormwater flooding and freezing rain. The expected annual damage of direct and secondary impacts attributed to freezing rain and stormwater flooding by 2040 are $30 million of GDP ($2013) and $70 million of GDP ($2013) respectively.

Given the potential costs facing municipalities, the analysis affirms the business case for investing in community-level adaptation measures.[66]

As part of developing a climate adaptation plan, the city of Edmonton completed an economic analysis of the future cost of potential climate impacts on the city. The analysis estimated an increase in costs of $8.0 billion by 2050 and $18.2 billion by 2080 compared to time of the study (year 2018). Costs considered included financial losses, health costs and environmental losses. The study predicts that Edmonton's GDP will be $3.2 billion and $7.4 billion lower by 2050 and 2080, respectively, compared to 2018, as a result of climate change impacts. The analysis found that costs for Edmonton increase with each degree of additional warming.[67]

APPENDIX C

Approach for Deriving GDP Estimates

To derive GDP estimates for the study locations, a GDP value from the respective province was scaled to the location using labour force statistics. More specifically, to tailor provincial data for regional use, GDP values were scaled to reflect the relative concentration of industry sectors in the region as compared to the province more broadly. The regionalization of GDP was performed by calculating location quotients (LQ) using Statistics Canada's Labour Force Survey data. An LQ is a ratio that compares labour force concentrations of industry sectors within a region (i.e., the study area) to a larger reference region (i.e., the province). LQs are calculated by comparing the industry's share of regional employment with its share of provincial employment as per the following equation:

$$LQ = \frac{e_i / e}{E_i / E}$$

where
e_i = local labour force population in industry i
e = total local labour force population
E_i = provincial labour force population in industry i
E = total provincial labour force population

By regionalizing the provincial GDP values using LQs, the analysts were able to derive GDP estimates that are reflective of the study areas under consideration (i.e., the study areas that correspond to the adaptation cost estimates in the database).

[66] Insurance Bureau of Canada. 2015. The Economic Impacts of the Weather Effects of Climate Change on Communities.
[67] City of Edmonton. 2018. Climate Resilient Edmonton: Adaptation Strategy and Action Plan.

List of Administrative Actions

18 additional staff to implement stormwater plan

Agency exercises to plan for large-scale wildfire

Assess and prioritize actions in Stormwater Management Master Plan

Assessment of natural aquifer

Change regulation to prohibit development in high-risk flooding zones

Communicate efforts to the public

Community preparation, response and recovery support

Complete the Business Continuity Plan

Conduct a detailed engineering vulnerability assessment

Conduct a heat wave vulnerability study

Conduct a regional groundwater assessment

Conduct a regional water planning process

Conduct a review of the 2010 Stony Plain hail event

Consider climate change in infrastructure design, construction, and maintenance

Continue shoreline impact education program

Crop management education program for farmers

Develop a Climate Resiliency Strategy

Develop a FireSmart education campaign

Develop a FireSmart program

Develop a long-term water management plan

Develop a map of all dugouts and water sources in the county

Develop a model for a Spruce Grove stormwater utility, paid for by local fees

Develop a regional team for emergency response planning

Develop a rural drinking water security plan

Develop a tree and vegetation management initiative

Develop a water conservation policy/bylaw

Develop a watershed hydrologic model, and continue lake monitoring program

Develop a wetland management plan

Develop a wetland protection incentive program

Develop an Asset Management Plan

Develop an Emergency Communications Plan

Develop an emergency education program

Develop an infiltration / in-flow control strategy

Develop an inter-municipal emergency evacuation plan

Develop an outdoor water use bylaw & restrictions

Develop and implement a policy for low impact development

Develop bylaw for residential discard into streets and catch basins

Develop comprehensive water plan

Develop education campaign for water conservation

Develop Master Drainage Strategy to retain natural drainage systems with a low-impact-develop approach

Develop public communications plan for water and sewer issues

Develop strategic plan for water preservation

Develop travel-to-work policy for city staff during extreme events

Develop water conservation education materials

Develop wetland and riparian area education program

Disseminate information on tornado preparedness to city staff

Educate residents on storm impacts and actions

Educate residents on stormwater drainage

Education campaign for stormwater awareness

Education materials on flood risk management best practices

Educational program for households

Encourage all farmers with water allocations to obtain water licenses

Encourage drought-tolerant landscaping

Encourage farmers to stockpile 2 years' supply of water and feed

Encourage use of non-potable water for all permitted uses

Enhance community education on wildfire risks and mitigation

Enhance contractor management to improve the resilience of scaffold systems

Enhance drought education

Enhance education on impacts to agriculture

Enhance internal and external stormwater management education programs

Enhance public awareness of the Emergency Preparedness Guide

Enhance the Regional Municipal Emergency Plan to deal with increasing wildfire risk

Evaluate municipal long-term drinking water storage

Event response and recovery

Examine feasibility of a flexible working policy for city staff

Expand and improve Emergency Response Plan

Explore connecting to regional ecological network for resiliency of Winnipeg and surrounding municipalities

Fire response preparedness

Foster resiliency of the city's natural landscape

Fund County Agriculture Department

Funding and convening support for watershed management planning

Hire a Municipal Emergency Plan (MEP) Coordinator

Identify and implement incentives to promote green infrastructure

Identify crops suitable for the future climate in the region

Identify new and existing best management practices for green infrastructure, land-use planning, and design

Identify wetlands to preserve, and develop techniques for temporary water storage using wetlands

Implement automatic water restrictions throughout the summer season

Improve and expand the existing Junior Forest Rangers Program

Improve flood mapping and develop a flood management plan

Improve inter-municipal wildland firefighting training

Improve landscaping policy education for municipalities and residents

Improve public education of emergency evacuation planning

Improve response times by cross-utilizing firefighting equipment and personnel

Include FireSmart policies in all planning and development

Include wildfire within emergency response plans

Increase agricultural land preservation through ALUS, county bylaws and policies

Increase collaboration efforts with producer and research groups

Increase standby emergency response staff

Integrating adaptation into operation & planning

Inventory local wetlands for stormwater management

Investigate the potential for greenhouses to support large-scale agricultural production

Launch a public awareness campaign to highlight opportunities for residential climate resilience initiatives

Lobby the provincial government for surface and groundwater quality monitoring

Modify water pricing mechanisms

Monitor projected water supply and water demand

Partner with local stewardship groups to promote water conservation and re-use

Promote wetland conservation and protection

Provide ongoing funding and support for adaptation projects

Provide tax incentives and rebates for fire proofing improvements

Raise public awareness of tornado precautions

Require hydration / cooling stations in planning application guide

Research post-disaster construction standards for new critical infrastructure

Research burying future transmission lines

Research future water sources and treatment options

Research groundwater and sources

Research need for tornado-safe spaces in existing civic facilities and buildings

Research trapping spring runoff for irrigation

Review and update County Emergency Response plans

Review and update disaster services policy

Review and update the snow and ice removal policy

Target economic development to low water use businesses

Train municipal staff

Update bylaws for appropriate water usage and pricing

Update Intensity-Duration-Frequency curves

Update Municipal Development Plan and subdivision standards to ensure retention of wetlands

Update municipal plans to support improved flood management and stormwater retention

Update stormwater engineering standards for future rainfall intensities

Update the Land Use Bylaw with FireSmart planning principles

Updated design standards for installation of stormwater infrastructure

Wildfire education, awareness, policy, and risk analysis

Community Profiling

Green Analytics examined the extent to which some of the data in the adaptation cost database might be reflective of a larger sample of communities in Canada. The approach employed for the examination involved taking several key characteristics of the communities in the database and identifying other communities with the same characteristics. This was done using data from Statistics Canada. A +/- 20% range from the population and land area of the target communities (i.e., the communities in the adaptation cost database) was applied to a larger geographic area to identify communities with similar populations and land areas. These communities were then filtered such that only communities facing similar climate risks were included (i.e., only coastal communities on the east coast meeting the population and land area criteria were included). The result was a list of communities facing a similar climate risk profile, with similar populations and similar land areas.

Profiling was done for the small east coast communities that are associated with the highest cost estimates in the database. Profiling was also done for the set of Alberta communities that have completed the Climate Resilience Express program and that have populations of less than 100,000.

The target east coast communities are Marystown, NL (population 5,316), Little Anse, NS (population 3,150) and Bay Bulls-Witless Bay, NL (population 3,119). These communities have adaptation cost to GDP ratios of 8.9, 6.2 and 14.0, respectively. Using the approach identified above, 20 communities with similar populations, land areas and climate risk profiles were identified. The adaptation cost to GDP ratios contained in the cost database (noted above) may be representative of the range of ratios that may be observed in these additional 20 communities. The communities and their populations are listed in Table E1.

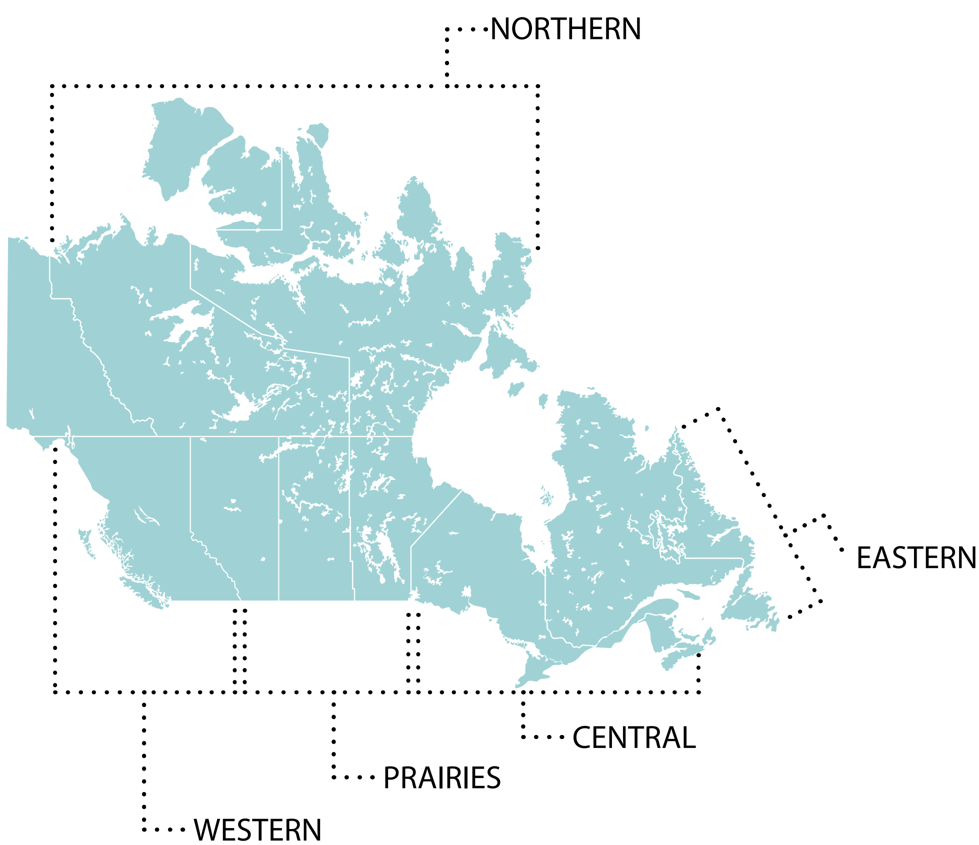


TABLE E1. EAST COAST COMMUNITIES WITH SIMILAR CLIMATE RISK PROFILE, LAND AREA AND POPULATION TO THREE COMMUNITIES IN COST DATABASE

COMMUNITY	PROVINCE	POPULATION
Bishop's Falls	NL	3156
Bonavista	NL	3448
Botwood	NL	2875
Carbonear	NL	4858
Channel-Port aux Basques	NL	4067
Deer Lake	NL	5249
Harbour Grace	NL	2995
Pasadena	NL	3620
Placentia	NL	3496
Spaniard's Bay	NL	2653
Springdale	NL	2971
Beresford	NB	4288
Caraquet	NB	4248
Dalhousie	NB	1067
Dalhousie	NB	3126
Sackville	NB	5331
Cornwall	PEI	5348
Westville	NS	3628
Kentville	NS	6271
Eskasoni 3	NS	3422

The Alberta communities for which profiling was done (i.e., those communities in the cost database that have completed the Climate Resilience Express program and that have populations of less than 100,000) are listed in the

TABLE E2. ALBERTA COMMUNITIES CONTAINED IN COST DATABASE FOR WHICH PROFILING WAS DONE

COMMUNITY NAME	POPULATION	COST TO GDP RATIO
Beaver County	5,905	0.0772
Big Lakes County	5,672	0.1621
Brazeau County	7,771	0.0605
Bruderheim	1,308	0.1000
Lacomb County	10,303	0.0395
Leduc	29,993	0.0220
Mackenzie County	11,171	0.0795
Spruce Grove	34,066	0.0084
Sylvan Lake	14,816	0.0415
Turner Valley & Black Diamond	5,259	0.0538

Using the climate risk profile, population data and land areas of these communities as guiding criteria, 134 communities from Saskatchewan, Manitoba, Ontario and Quebec were identified. The adaptation cost to GDP ratios presented in Table E2 above may be representative of this larger sample of communities in Canada (Table E3).

TABLE E3. COMMUNITIES WITH SIMILAR CLIMATE RISK PROFILE, LAND AREA AND POPULATION TO ALBERTA COMMUNITIES IN COST DATABASE

COMMUNITY NAME	PROVINCE	POPULATION
Terrasse-Vaudreuil	QC	1,986
Saint-Joseph-de-Sorel	QC	1,642
Vaudreuil-sur-le-Lac	QC	1,341
Osler	SK	1,237
Wendake	QC	2,134
Attawapiskat 91A	ON	1,501
Waldheim	SK	1,213
Cobalt	ON	1,128
Lac du Bonnet	MB	1,089
Arborg	MB	1,232
Birch Hills	SK	1,033
Dalmeny	SK	1,826
Uashat	QC	1,592
Gull Lake	SK	1,046
Deseronto	ON	1,774
Price	QC	1,759
St-Pierre-Jolys	MB	1,170
Pointe-des-Cascades	QC	1,481
Chemawawin 2	MB	1,252
Carnduff	SK	1,099
Kipling	SK	1,074
Eston	SK	1,061
Huntingdon	QC	2,444
Saint-Gabriel	QC	2,640
Grenville	QC	1,711
Wadena	SK	1,288
Redvers	SK	1,042
Englehart	ON	1,479
Melita	MB	1,042
Preeceville	SK	1,125
Fort-Coulonge	QC	1,433
Stanley 157	SK	1,840

COMMUNITY NAME	PROVINCE	POPULATION
Macklin	SK	1,374
Grenfell	SK	1,099
Indian Head	SK	1,910
Factory Island 1	ON	1,560
Lac-Simon	QC	1,380
Oxbow	SK	1,328
Teulon	MB	1,201
Point Edward	ON	2,037
Gravelbourg	SK	1,083
Delisle	SK	1,038
Moose Lake 31A	MB	1,124
Langenburg	SK	1,165
Mattawa	ON	1,993
Shellbrook	SK	1,444
Assiniboia	SK	2,389
Winnipeg Beach	MB	1,145
Regina Beach	SK	1,145
Langham	SK	1,496
Lumsden	SK	1,824
South River	ON	1,114
Notre-Dame-du-Bon-Conseil	QC	1,557
Ste. Anne	MB	2,114
Bedford	QC	2,560
Rosthern	SK	1,688
Sainte-Pétronille	QC	1,033
Maple Creek	SK	2,084
Davidson	SK	1,048
Thessalon	ON	1,286
Maidstone	SK	1,185
Esterhazy	SK	2,502
Roxton Falls	QC	1,305
Carberry	MB	1,738
Balgonie	SK	1,765
Powerview-Pine Falls	MB	1,316
Shaunavon	SK	1,714
Fort Qu'Appelle	SK	2,027
Wynyard	SK	1,798
Maliotenam	QC	1,542
Sainte-Madeleine	QC	2,233
Shawville	QC	1,587

COMMUNITY NAME	PROVINCE	POPULATION
Valcourt	QC	2,165
Pelican Narrows 184B	SK	1,869
Ayer's Cliff	QC	1,047
Carlyle	SK	1,508
Pilot Butte	SK	2,137
Kamsack	SK	1,898
Ville-Marie	QC	2,584
Air Ronge	SK	1,106
Foam Lake	SK	1,141
Morris	MB	1,885
Thurso	QC	2,818
Cross Lake 19A	MB	1,922
Curve Lake First Nation 35	ON	1,059
Disraeli	QC	2,336
Pinehouse	SK	1,052
Chute-aux-Outardes	QC	1,563
Canora	SK	2,024
Moosomin	SK	2,743
Outlook	SK	2,279
Manawan	QC	2,060
Kimosom Pwatinahk 203 (Deschambault Lake)	SK	1,061
Lanigan	SK	1,377
Kerrobert	SK	1,026
Obedjiwan	QC	2,019
East Broughton	QC	2,199
Lac La Ronge 156	SK	2,017
Kettle Point 44	ON	1,011
Wilkie	SK	1,219
Unity	SK	2,573
Desbiens	QC	1,028
Léry	QC	2,318
Corman Park No. 344	SK	8,568
Portage la Prairie	MB	6,975
Thompson	MB	13,678
Brockville	ON	21,346
Dorval	QC	18,980
Tillsonburg	ON	15,872
Cobourg	ON	19,440
Joliette	QC	20,484
Owen Sound	ON	21,341

COMMUNITY NAME	PROVINCE	POPULATION
Beloeil	QC	22,458
Portage la Prairie	MB	13,304
Chambly	QC	29,120
Steinbach	MB	15,829
Boisbriand	QC	26,884
Stratford	ON	31,465
Orillia	ON	31,166
Swift Current	SK	16,604
North Battleford	SK	14,315
Collingwood	ON	21,793
Prévost	QC	13,002
Midland	ON	16,864
St. Thomas	ON	38,909
Saint-Basile-le-Grand	QC	17,059
Yorkton	SK	16,343
Saint-Bruno-de-Montarville	QC	26,394
La Prairie	QC	24,110
Mont-Saint-Hilaire	QC	18,585
Mercier	QC	13,115
Cowansville	QC	13,656
Sainte-Julie	QC	29,881
Moose Jaw	SK	33,890

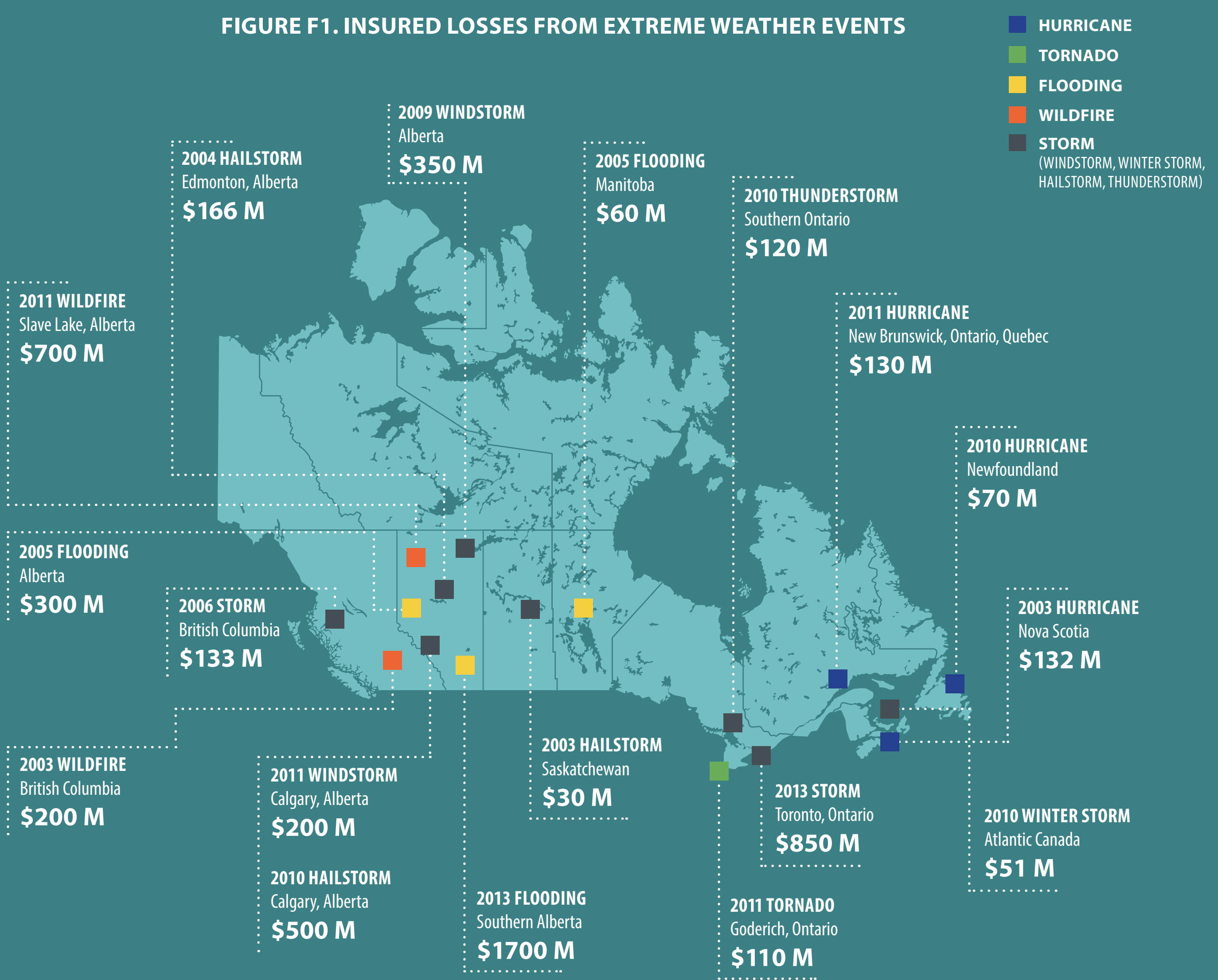
APPENDIX F

Municipal Costs of Extreme Weather

THE COSTS OF RECENT EXTREME WEATHER EVENTS

Weather changes in Canada are happening abruptly with more communities experiencing extreme weather events.[68] The Canadian Meteorological and Oceanographic Society reports that heat waves, extreme flooding and wildfires are becoming more frequent and severe. Environment and Climate Change Canada, for example, has concluded that the risk of western fires since 2015 has increased two to six times due to human-induced warming.[69] The resulting impacts of extreme weather events are placing a financial strain on communities, businesses and all levels of government. In this section, we demonstrate the benefits of adaptation by highlighting examples of the economic costs associated with recent extreme weather events (see Appendix B for an overview of studies that have estimated the future cost of climate change impacts). A map of insured losses due to extreme weather events in Warren and Lemman (2014), provides historical context, documenting the costliest impacts between 2004 and 2013 (Figure F1). The map includes events up to July 2013 so does not include the flooding in Southern Alberta or the ice storm in Eastern Ontario.

FIGURE F1. INSURED LOSSES FROM EXTREME WEATHER EVENTS



Source: Warren, F.J. and Lemmen, D.S. 2014. Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.

[68] Canadian Meteorological and Oceanographic Society. 2016. Canada's Top Weather Stories for 2018.

[69] Reported Canadian Meteorological and Oceanographic Society. 2016. From, Environment and Climate Change Canada. 2017. Climate Data and Scenarios for Canada: Synthesis of Recent Observation and Modelling Results. Chapter 3.3: Extremes.

The year 2013 was a landmark year, as insurance companies incurred over $3.2 billion in losses due to extreme weather events, a record high, which at the time dramatically exceeded previous highs. Below, three events that occurred in 2013 are highlighted to demonstrate the magnitude of economic impacts from climate change and the importance of adaptation measures. The 2013 events are the flooding in Southern Alberta, the July rainfall event in Toronto, and the December ice storm in Ontario. The two extreme weather events hitting Toronto in 2013 demonstrate the financial burden that multiple extreme weather events can have on municipalities. The combined costs incurred by the city were over $171 million. A new record in insurance losses was set in 2016, attributed largely to the Fort McMurray fires, which is now the costliest natural disaster ever in Canada.[70] In addition, two examples of other recent extreme weather events, floods in Essex County, Ontario, and the 2018 Saint John river flood, demonstrate the financial toll these events are having and the need to ramp up adaptation measures in communities across Canada.

The benefits of these adaptation measures have been acknowledged by local decision makers. According to Tecumseh Mayor Gary McNamara, "[b]y making flood mitigation improvements, not only do we prevent flooding for our townsfolk, we also save money by sending less water to Windsor to be treated."[71] The leaders in the communities ravaged by the extreme rains of 2016 and 2017 recognize the importance of keeping water in the ground, holding and controlling its flow and redirecting it away from the sewer system.[72] In this regard, the use of green infrastructure is an important part of the solution. Lakewood Park, for example, is a parcel of land bought by the town of Tecumseh at a cost of $15 million. It rests above a water reservoir and large sanitary sewers and is integrated with a storm channel and pumping station. The park is an important part of the flood adaptation strategy for the community.

[70] Insurance Bureau of Canada. 2014. Canada inundated by severe weather in 2013: Insurance companies pay out record breaking $3.2 billion to policyholders. January 20th, 2014.
[71] https://windsorstar.com/news/local-news/a-year-after-the-flood-municipalities-spending-millions-to-mitigate-future-damage
[72] https://windsorstar.com/news/local-news/a-year-after-the-flood-municipalities-spending-millions-to-mitigate-future-damage

FORT MCMURRAY FIRE, MAY 2016

The Fort McMurray fire in May of 2016 displaced Fort McMurray's 88,000 residents, damaged or destroyed 1,935 residential structures, 23 commercial and industrial buildings, and scorched 18,600 vehicles.[73] The Conference Board of Canada estimated the total direct cost of the disaster, including private expenditures, at $5.4 billion. This includes $3.8 billion in insured losses, $1.2 billion in payments from federal, provincial and municipal governments to help with the cleanup and rebuilding, and $500 million in costs incurred by the private sector and households. In addition, the Alberta Government spent $369 million in extra wildfire-fighting costs.[74] The estimated $3.8 billion in insured losses makes it the costliest natural disaster for Canadian insurers ever. Catastrophe Indices and Quantification Inc. estimated the breakdown of insurance losses as follows: 27,000 personal property claims; 5,000 commercial claims; and 12,000 car claims.[75]

The fire caused substantial economic disruption to the Wood Buffalo region and resulted in temporary shutdowns to oil sands operations. Real (inflation-adjusted) GDP in the Wood Buffalo region was estimated to have declined by 14.6 per cent in 2016 due to the fire. Shutdowns of oil sands production created losses of 47 million barrels of oil and cost producers $1.4 billion in revenues.[76,77] Other economic costs include $300 million in lost taxes and royalties to the province, $167 million in lost federal taxes, $458 million in lost labour income and $55 million in lost revenue to Fort McMurray businesses.[78]

While the emphasis is on the direct cost of the fires, the toll on the community in terms of health impacts was substantial as well. For example, Agyapong and colleagues (2018) in a study on depression prevalence of Fort McMurray residents following the 2016 wildfires found a fourfold increase in the point prevalence of major likely depressive disorders when compared to the general population in the province. The prevalence rate of major likely depressive disorders 6 months after the disaster was 14.8% compared to the 3.3% prevalence rate in the general public in Alberta. The study also identified a significant twofold or greater likelihood of suffering from problematic drug use, harmful or hazardous drinking or alcohol dependence, or moderate to high nicotine dependence among those suffering from likely depression.[79]

[73] Canadian Meteorological and Oceanographic Society. 2016. Canada's Top Weather Stories for 2016.
[74] McIntyre, Jane. Moving Forward: The Economic Impact of Rebuilding the Wood Buffalo Region's Economy. Ottawa: The Conference Board of Canada, 2017.
[75] Canadian Underwriter Magazine. 2017. Government of Alberta advances Disaster Recovery Program funding to help with Fort McMurray uninsurable costs. February 17, 2017.
[76] McIntyre, Jane. Moving Forward: The Economic Impact of Rebuilding the Wood Buffalo Region's Economy. Ottawa: The Conference Board of Canada, 2017.
[77] Conference Board of Canada. 2016. Fort McMurray Wildfires: Assessing the Economic Impacts. Briefing November 2016.
[78] Reporting research by Dr. Rafat Alam (MacEwan University). Canadian Press. 2017. Almost $10B: Research outlines costs of Fort McMurray wildfire. January 17th, 2017.
[79] Agyapong, V., Juhás, M., Brown, M., Omege, J., Denga, E., Nwaka, B., Akinjise, I., Corbet,t S., Hrabok, M., Li, X., Greenshaw, A., & Chue, P. 2019. Prevalence rates and correlates of probable major depressive disorder in residents of Fort McMurray 6 months after a wildfire. Int J Mental Health Addict, 17:120–136.

TORONTO, ONTARIO ICE STORM, DECEMBER 21-22, 2013

While the 2013 ice storm impacted Eastern Ontario, parts of Quebec and New Brunswick, the Toronto area was among the hardest hit regions by the storm. Over 300,000 customers in the Greater Toronto Area (GTA) lost electrical power, and many households and businesses lost power for several days. Transportation systems came to a halt. Forty percent of power transmission lines were affected, while more than 20% of the City of Toronto's tree canopy was destroyed.[80] The winter storm event cost City of Toronto divisions, agencies and corporations over $106 million.[81] Table F1 provides a breakdown of costs by service provider. In addition to costs incurred directly by the city, the federal government contributed $120 million under the DFAA program to offset recovery and repair costs.[82] Insurance losses were estimated to cost over $200 million.[83]

TABLE F1. SUMMARY OF DECEMBER 21-22 WINTER STORM COST ESTIMATES

CITY OF TORONTO SERVICES	TOTAL COSTS ($)
Parks, Forestry and Recreation (1)	52,213,000
Employment and Social Services	1,009,000
Transportation Services (2)	8,802,961
Toronto Water	1,506,560
Solid Waste Management Services (3)	24,474,797
Other city divisions	1,703,477
Toronto Hydro (4)	13,900,000
Toronto Police Service	245,000
Toronto Transit Commission (5)	700,000
Toronto Library	53,996
Toronto Community Housing	2,145,337
Toronto Zoo	187,000
Total	**106,941,128**

Notes:
(1) Forestry costs consist mainly of emergency response including removal of tree limbs affecting hydro wires ($1.8M), inspection and elimination of hazards on streets, parks, sidewalks, roads, entrances to centres ($30.4M), inspect and assess remedial work, canopy repair, stump removal and tree replacement ($16.6M). As well, estimated damage to Parks assets ($2.1M) and loss of revenue for recreation centres and costs for staffing and supplies at warming centres ($1.3M)
(2) Transportation Services costs consist mainly of clean up of road hazards ($7.1M), and emergency responses ($1.2M)
(3) Solid Waste Management costs consist mainly of chipping wood ($6.2M), haulage of wood from curbside ($16.2M), creation of temporary storage sites ($1.5M), and miscellaneous ($0.5).
(4) Toronto Hydro costs consist mainly of costs to restore power ($12.9M), and lost revenues ($1M).
(5) TTC estimated costs do not include revenue losses.
Source: City of Toronto. 2014.

[80] Toronto Public Libraries. 2016. Remembering the December 20-23, 2013 Ice Storm: Snapshots in History. December 28, 2016
[81] City of Toronto. 2014. Staff Report: Impacts from the December 2013 Extreme Winter Storm Event on the City of Toronto. January 8th, 2014.
[82] Parliamentary Budget Officer of Canada. 2016. Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events.
[83] City of Toronto. 2014. Staff Report: Impacts from the December 2013 Extreme Winter Storm Event on the City of Toronto. January 8th, 2014.

TORONTO, ONTARIO RAINFALL EVENT, JULY 2013

Record rainfall on July 8, 2013 caused severe flooding in Toronto. More than ninety millimetres of rain fell in a two-hour period. Subways were closed due to flooding, GO trains were evacuated by police boats, and drivers faced washed-out roads.[84]

The rainfall event resulted in more than $850 million in insured property losses across the GTA. A City of Toronto assessment of the storm-related costs estimated the city (municipal government) incurred $59.2 million in capital costs and $10.9 million in operating costs associated with response and recovery (Table F2).[85]

TABLE F2. ECONOMIC COSTS, JULY 8TH STORM EVENT

CITY STORM RELATED COSTS	OPERATING ($)			CAPITAL ($)	TOTAL COSTS ($)
	EXPENDITURE	REVENUE LOSSES INCURRED	TOTAL OPERATING IMPACT	TOTAL CAPITAL IMPACT	OPERATING AND CAPITAL
Toronto Water	1,704,755	-	1,704,755	6,843,100	8,547,875
Parks, Forestry and Rec.	2,116,370	207,507	2,323,877	10,360,208	12,684,085
Other City Divisions	4,115,546		4,115,546	2,843,971	6,959,517
Agencies and corporations	1,844,926	920,157	2,765,083	3,125,668	5,890,751
TRCA	3,600	-	3,600	36,050,014	36,053,614
Total	**9,785,217**	**1,127,664**	**10,912,881**	**59,222,961**	**70,135,842**

Source: City of Toronto. 2013.

The storm had a wide economic impact causing major transit delays, road closures, power outages, flight cancellations and business closures lasting in many cases several days to deal with flood recovery and clean-up.

The combination of the Toronto December ice storm (discussed above) and July rainfall event resulted in losses and costs to the city of over $171 million. The events placed substantial financial strain on the city to address budget shortfalls.[86]

[84] Casello, J., and Towns, W. 2017. Urban. In K. Palko and D.S. Lemmen (Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 264-309). Ottawa, ON: Government of Canada.
[85] City of Toronto. 2013. Staff Report: Follow-up on the July 8, 2013 Storm Event.
[86] City of Toronto. 2014. Staff Report: Impacts from the December 2013 Extreme Winter Storm Event on the City of Toronto. January 8th, 2014.

SOUTHERN ALBERTA FLOODING, JUNE 2013

The 2013 flood in Southern Alberta damaged an estimated 4,000 businesses and 13,500 homes. One hundred thousand people were evacuated and five people died. The flood caused extensive damage to infrastructure, with 1,000 km of roads destroyed and hundreds of bridges and culverts washed out.[87] In total, an estimated 278 cities, towns and villages were affected.[88]

The flood was estimated to cost over $6 billion in capital losses of which about $2 billion represented insured losses.[89] The federal government contributed $1.35 billion under the DFAA program to support flood recovery. In addition, the City of Calgary, one of the hardest hit regions, received $55 million in direct federal support to help repair damaged infrastructure and to pay for the costs of emergency response and staff.[90]

SAINT JOHN RIVER FLOOD, 2018

While seasonal flooding is a common occurrence along the Saint John River in New Brunswick, the 2018 flood was well beyond the realms of normality for the river. The flooding occurred in early April and was the result of the winter accumulation of snow colliding with extremely warm temperatures and significant rainfall within a 48 hour period. Temperatures in the province reached 29°C immediately before a heavy rainstorms moved into the province. Rain fell for 31 of 32 days and totalled 152 mm. The result was water in the Saint John River rising 2 metres above flood levels.[91] Water levels in the capital city were more than 8 metres above sea level.[92] The trifecta of conditions culminated in the largest, most impactful flood in modern New Brunswick history. The impact to public infrastructure was significant as the Trans-Canada Highway between Fredericton and Moncton was closed along with over 150 roads, bridges, and culverts across the province.[93]

When the Saint John River flooded in 2008, more than $23 million in damages were incurred as over 600 properties were impacted and 1,000 people were displaced from their homes. At the time, it was the worst spring flood since 1973.[94] The impact from the 2018 spring flood far exceeded that of 2008. In 2018, 12,000 properties were impacted. The cost to the federal and provincial government was $80 million.[95] The 2018 flood became the most damaging flood in New Brunswick in more than 50 years.[96]

FLOODS IN ESSEX COUNTY, ONTARIO, 2016 AND 2017

In September 2016, Essex County, Ontario experienced extreme rainfall. The volume of rainfall varied by neighbourhood, but exceeded 200 mm in some communities (e.g., Riverside and Tecumseh). In Windsor, the city's stormwater infrastructure could not manage the deluge of water; the volume was well beyond the maximum capacity of the system. The result was inundated roads, fields and yards as well as dirty sewer water in flooded basements. Over 6,000 insurance claims were made as a result of the 2016 rainfall event.[97] The total cost of such claims was over $153 million. Of course, the insurance costs are a fraction of the total costs. Recall that for every dollar spent on insurance, $3 to $4 are incurred by governments, households and businesses.

[87] Andrey, J., and Palko, K. (2017). Introduction. In K. Palko and D.S. Lemmen (Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 2-10). Ottawa, ON: Government of Canada.
[88] Davies, J. 2016. Economic analysis of the costs of flooding. Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 41:1-2, 204-219.
[89] Alberta Water Portal Society. Economic Impacts of Flooding. Available online: albertawater.com/what-are-the-consequences-of-flooding/economic#ftnt2.
[90] Expert Management Panel on River Flood Mitigation. 2014. "Calgary's Flood Resilient Future." Calgary, AB: Expert Management Panel on River Flood Mitigation.
[91] https://bulletin.cmos.ca/canadas-top-ten-weather-stories-of-2018/
[92] https://www.cbc.ca/news/canada/new-brunswick/fredericton-closes-streets-as-flood-waters-rise-1.754450
[93] https://bulletin.cmos.ca/canadas-top-ten-weather-stories-of-2018/
[94] https://www.cbc.ca/news/canada/new-brunswick/st-john-river-flood-2018-monday-1.4641176
[95] https://www.cbc.ca/news/canada/new-brunswick/flood-new-brunswick-2018-1.4668529
[96] https://www.macintyrepurcell.com/books/new/new-brunswick-underwater-the-2018-saint-john-river-flood-1-detail
[97] https://www.cmos.ca/site/top_ten?a=2016&language=en_CA

Less than a year later, on August 28, 2017, another extreme rain event hit the region flooding the same area. Within 48 hours, 222 mm of rain had fallen in southwest Windsor and 140 mm to 200 mm in Riverside-Tecumseh. The neighbouring community of LaSalle was hit even harder when 125 mm of rain fell on August 28 and another 160 mm of rain fell the next day. In total, 285 mm of rain fell on LaSalle in 32 hours.[98]

Once again, stormwater infrastructure in these neighbourhoods and communities was overpowered as rainwater smothered roads, fields and yards and filled thousands of basements. Insurance payouts for the 2017 rain event totaled $165 million – the most expensive single-storm loss across Canada that year. In addition to insurance claims, the province of Ontario paid out another $1.4 million through the provincial Disaster Recovery Fund.[99] Between the two events, 11,000 households experienced flooding.

Factors that contributed to the record breaking claims and high cost of these extreme rainfall events include climate change, the disappearance of wetlands and aging infrastructure.[100] In response, municipalities are investing millions of dollars ($120 million as of September 2018) in adaptation measures including improvements to sewer systems, modified roads to support overland water flows, and upgrades to pumping stations in the hardest hit neighbourhoods.[101,102] Infrastructure upgrades to manage extreme volumes of water that are underway in the municipalities include:[103]

- A nearly $90-million plan for the Riverside area that includes sewer replacements, upgrades to pumping stations and sewers and rebuilding roads.
- Improvements to the Lennon Drain in South Windsor and the Riverside Vista project, both of which will aid storm water management.
- A $30.3-million plan for Tecumseh to cover the Manning Road ditches and improve sewers and pump capacity along Riverside Drive.
- A $3-million project in LaSalle to turn a park and sports recreational area into a dry pond in the Heritage Estates and Oliver Farm areas.
- Lakeshore's priorities are making improvements in its sewers and pump capacity in the western end of the town that got hit hard in 2016 and 2017 and to expand its wastewater treatment plan.

[98] https://www.cmos.ca/site/top_ten?a=2016&language=en_CA
[99] https://www.insurancebusinessmag.com/ca/news/flood/windsor-flooding-one-year-on-what-were-the-lessons-learned-110051.aspx
[100] https://www.insurancebusinessmag.com/ca/news/flood/windsor-flooding-one-year-on-what-were-the-lessons-learned-110051.aspx
[101] http://www.windsorpubliclibrary.com/?page_id=63749
[102] https://windsorstar.com/news/local-news/a-year-after-the-flood-municipalities-spending-millions-to-mitigate-future-damage
[103] https://windsorstar.com/news/local-news/a-year-after-the-flood-municipalities-spending-millions-to-mitigate-future-damage

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