REPORT

Canada in a Changing Climate

National Issues

Government of Canada / Gouvernement du Canada

Canada

Canada in a Changing Climate: National Issues Report

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Foreword

NATIONAL ISSUES REPORT

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Foreword

Three years ago, when we started working on Canada's current National Knowledge Assessment process, *Canada in a Changing Climate: Advancing our Knowledge for Action*, we could never have imagined how different the world would be at the time of release of this report. Since early 2020, we have lived through rapid and unprecedented change as the global population has struggled to respond to the COVID-19 pandemic. All aspects of our lives have been affected—health and well-being, social connections, jobs, economic stability and more.

Although dealing with the COVID-19 pandemic has dominated the world's attention, the issue of climate change remains firmly embedded in many global, national and sub-national dialogues. Indeed, while we are still trying to understand the pandemic shocks that are rippling through our social, economic and environmental systems, some encouraging insights are emerging that are relevant to responding to climate change. The response to COVID-19 thus far has shown that once individuals, businesses and governments understand the risks, they are willing to make major changes to protect lives and livelihoods, even in the face of uncertainty. The experience of the past year has also demonstrated the advantages that can be realized through cooperation, the progress that can be achieved through aligned efforts, and the critical role that the private sector and civil society play in responding to global challenges.

There is abundant research indicating that current efforts to adapt are insufficient in the face of rapidly accumulating social and economic losses from current and future climate change impacts. The research also demonstrates that the window for taking action to reduce increasingly severe impacts is rapidly closing. Urgent action, supported by strong investments, is needed to both reduce greenhouse gas emissions and to increase resilience to climate change through adaptation. Our decisions and actions today will determine our ability to survive and thrive under a changing climate. Informed decisions, drawing from the best science and knowledge available at the time, are imperative.

Within this context, we are pleased to release the *National Issues Report*. This report, led by Natural Resources Canada, is part of Canada's National Knowledge Assessment process, *Canada in a Changing Climate: Advancing our Knowledge for Action*. The report provides a national perspective on how climate change is impacting our communities, environment and economy, and how we are adapting to reduce risks. It includes chapters on topics that are of national importance or that benefit from a pan-Canadian perspective, along with case stories featuring examples of adaptation in practice.

Within the larger National Knowledge Assessment process, the *National Issues Report* follows the release of *Canada's Changing Climate Report* in 2019 and the Prairie Provinces chapter of the *Regional Perspectives Report* in December 2020. Other regional chapters—including Northern Canada, British Columbia, Ontario, Quebec and Atlantic Provinces—will also be released over the coming year.

The overarching goal of the National Knowledge Assessment process is to assess, synthesize and share the latest knowledge on climate change impacts and adaptation in Canada. We hope that this report, as well as those that follow, will inspire you to take timely and meaningful actions for adapting to climate change and equip you with the information you need to do so.

The National Knowledge Assessment Advisory Committee

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Report Overview

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Introduction

Canada's changing climate is causing deep and lasting impacts on our society, economy and environment. Higher temperatures, shifting rainfall patterns, extreme weather events and rising sea levels are just some of the changes already affecting many aspects of our lives. Changes in climate will persist and, in many cases, will intensify over the coming decades. Understanding these impacts is necessary to reduce risks, build resilience and support sound decision-making.

In 2017, the Government of Canada launched the National Knowledge Assessment process, *Canada in a Changing Climate: Advancing our Knowledge for Action*. This multi-year, collaborative initiative is delivering a series of authoritative reports (*see* Figure 0.1) that focus on how and why Canada's climate is changing, the impacts of these changes and how we are adapting.

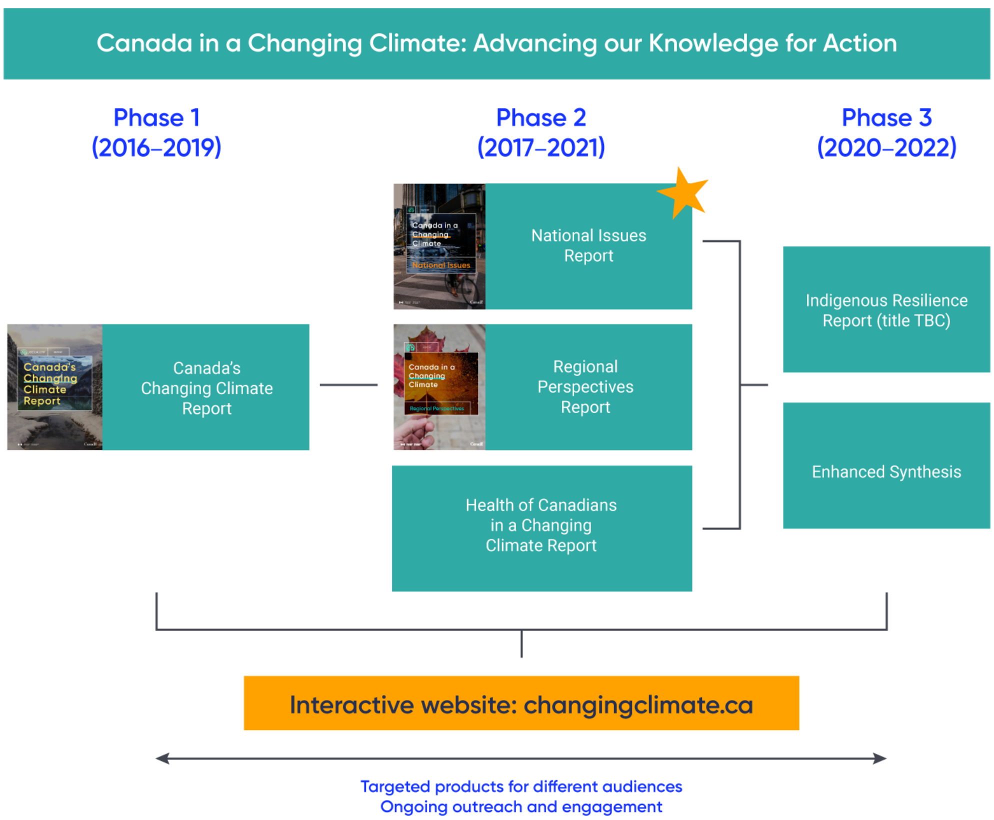


Figure 0.1: An overview of the products being produced under *Canada in a Changing Climate: Advancing our Knowledge for Action*. Natural Resources Canada is leading the process and depends on the collaboration of a broad partnership of subject-matter experts and assessment users, including from all orders of government, Indigenous organizations, universities, professional and non-governmental groups, and the private sector. To learn more about the assessment process, visit adaptation.nrcan.gc.ca.

The first report in the series, *Canada's Changing Climate Report* (CCCR), was released in 2019. It assessed Canada's changing climate, covering observed and projected changes in temperature, precipitation, snow, ice, permafrost and freshwater availability, including changes in Canada's three oceans (see Box O.1).

Box O.1: Headline Statements from *Canada's Changing Climate Report*

Canada's Changing Climate Report included 10 headline statements that tell a concise story about the changing climate in Canada. The statements are summarized below:

1. Canada's climate has warmed and will warm further in the future, driven by human influence.
2. Both past and future warming in Canada is, on average, about double the magnitude of global warming.
3. Oceans surrounding Canada have warmed, and have become more acidic and less oxygenated, which is consistent with observed global ocean changes over the past century.
4. The effects of widespread warming are evident in many parts of Canada and are projected to intensify in the future.
5. Precipitation is projected to increase for most of Canada, on average, although summer rainfall may decrease in some areas.
6. The seasonal availability of freshwater is changing, with an increased risk of water supply shortages in summer.
7. A warmer climate will intensify some weather extremes in the future.
8. Canadian areas of the Arctic and Atlantic Oceans have experienced longer and more widespread sea-ice-free conditions.
9. Coastal flooding is expected to increase in many areas of Canada due to local sea level rise.
10. The rate and magnitude of climate change under high versus low emission scenarios project two very different futures for Canada.

Note: The full Headline Statements can be found at changingclimate.ca, and each statement is cross-referenced to specific sections in chapters of the main report, where supporting evidence can be found. There is high confidence or more associated with each of these statements, which are consistent with, and draw on, the Key Messages in the chapters.

The *National Issues Report* builds on the CCCR, providing answers to questions such as:

- What do these changes in climate mean for those living in Canada?
- How can we adapt to increase resilience, reduce risks and costs, and take advantage of potential opportunities?

- Where have we made progress on addressing climate change impacts and adaptation?
- Where do gaps in knowledge and action remain?

The *National Issues Report* focuses on climate change impacts and adaptation issues that are of national importance or that are best understood through an integrated, pan-Canadian perspective. It is structured around the main elements of sustainability—society, the environment and the economy—and includes a chapter on international dimensions.

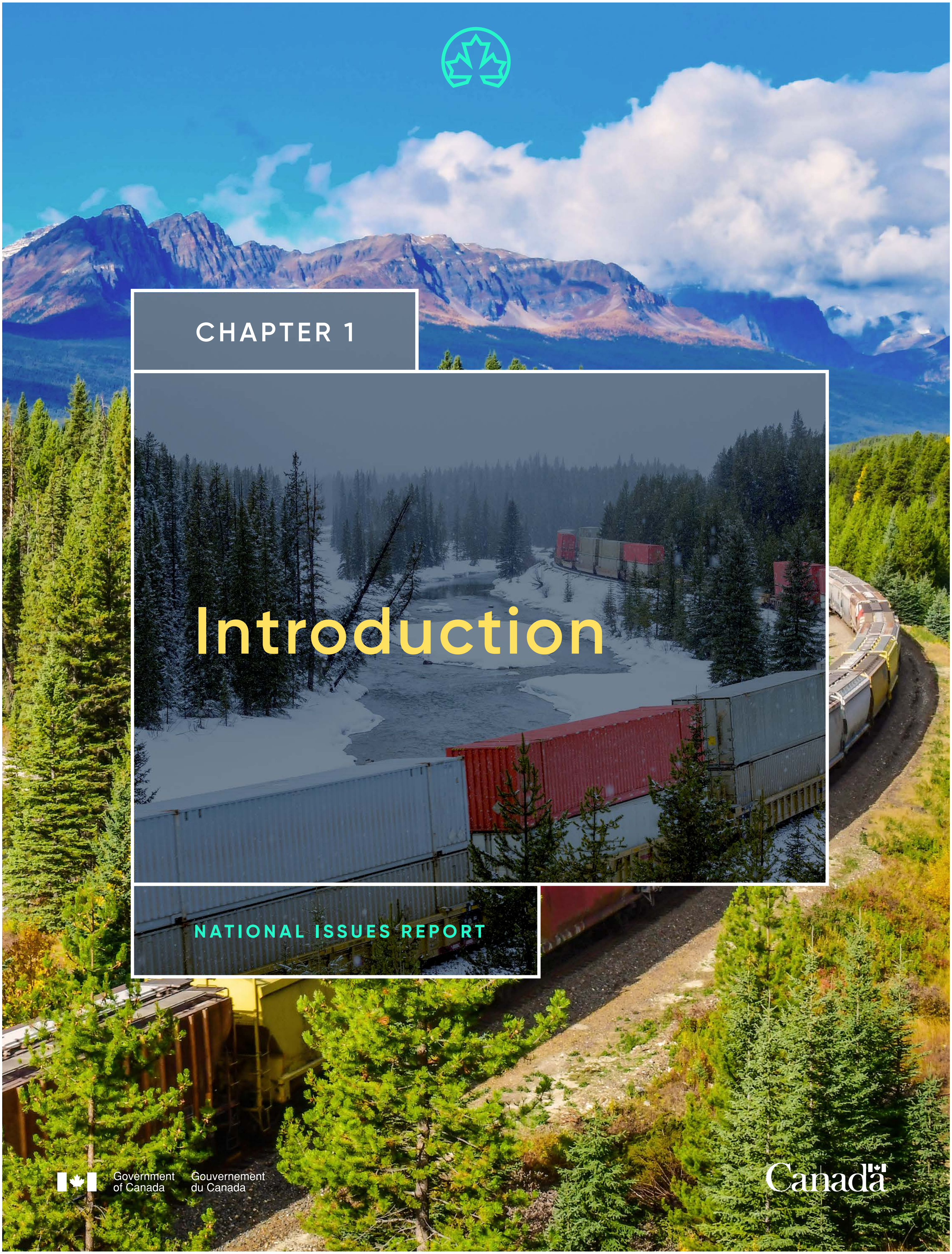
Key findings of the *National Issues Report*

1. **Communities of all sizes across the country are experiencing the impacts of climate change on their infrastructure, health and well-being, cultures and economies.** Local action to reduce climate-related risks is increasing, although limited capacity is challenging the ability of many communities to act (*see* Cities and Towns chapter; Rural and Remote Communities chapter).
2. **Changes in climate are threatening the vital services that Canada's ecosystems provide and are negatively impacting our water resources.** Effective coordination, cooperation and adaptive management, as well as conservation efforts, can help to reduce impacts. Nature-based approaches to adaptation that maintain or restore ecosystems, such as wetlands, are a cost-effective and sustainable means of moderating climate change impacts and building resilience (*see* Ecosystem Services chapter; Water Resources chapter; Cities and Towns chapter).
3. **While climate change will bring some potential benefits, overall it will impose increasing economic costs on Canada.** A changing climate affects all sectors of Canada's economy through impacts on production, operations and/or disruption to supply chains. Disclosure of climate-related risks is emerging as a key driver of adaptation in the private sector (*see* Sector Impacts and Adaptation chapter; Costs and Benefits of Climate Change Impacts and Adaptation chapter; Climate Disclosure, Litigation and Finance chapter).
4. **We must look beyond our borders when assessing the impacts of a changing climate for Canada.** Climate change impacts occurring elsewhere in the world, as well as the steps that other countries take—or do not take—to adapt, can strongly affect food availability, trade and immigration. These impacts place additional stress on Canada's communities, businesses and government services (*see* International Dimensions chapter).
5. **Large gaps remain in our preparedness for climate change, as demonstrated by recent impacts of extreme weather events, such as floods and wildfires.** Accelerating progress on adaptation through rapid and deliberate plans and actions is vital for Canada's economic and social well-being (all chapters).
6. **Lessons on good practices are continuing to emerge and are helping to guide successful adaptation.** These include empowering strong leadership, collaborating broadly and adopting flexible management approaches. Incorporating diverse perspectives and sources of knowledge, such as Indigenous Knowledge Systems, is also imperative for effective adaptation (all chapters).

Moving forward

As the world responds to the COVID-19 pandemic, new insights are emerging that are relevant to climate change adaptation. Considerable optimism can be derived from the global response. It has shown that once individuals, businesses and governments understand the risks associated with COVID-19, they are willing to make major changes to protect lives and livelihoods, even when faced with uncertainty. It has also demonstrated the importance of action at every level, the advantages that can be achieved through cooperation across multiple levels of government, and the critical role of both the private sector and civil society. It is important to note that the content of the chapters in this report was finalized prior to the start of the pandemic. The chapters therefore do not address the impacts of the pandemic or any potential relationships between climate change and COVID-19.

There is abundant research indicating that current efforts to adapt are insufficient in the face of rapidly accumulating social and economic losses from current and future climate change impacts. The research also demonstrates that the window for taking action to reduce increasingly severe impacts is rapidly closing (Rogelj et al., 2019; IPCC, 2018). Urgent action, supported by strong investments, is needed to both reduce greenhouse gas emissions and to increase resilience to climate change through adaptation. Decisions taken today will determine the degree of future changes and our resilience to climate risks. Evidence-based decisions are imperative for minimizing costs, protecting lives and livelihoods, and ensuring a sustainable future for Canadians.



CHAPTER 1

Introduction

NATIONAL ISSUES REPORT

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1.1 Introduction

In 2014, the Intergovernmental Panel on Climate Change (IPCC) stated that "warming of the climate system is unequivocal" (IPCC, 2014). Since then, evidence of change has continued to build, with observed increases in temperature (over land and oceans), rising sea levels, loss of snow and ice, and shifting precipitation patterns at the global scale (e.g., IPCC, 2018; 2019; USGCRP, 2018). Many of the changes brought about by increases in temperature are unprecedented, and most are projected to persist and intensify over the current century (Bush et al., 2019; IPCC, 2014). A clearer picture of the impacts is also emerging, with recognition that climate change has the potential to affect almost every aspect of our lives—our health and well-being, economies, environment, and even our identities and sense of self. It is also increasingly clear that the impacts are not evenly distributed, and that certain regions, populations and groups are being disproportionately affected.

We are also seeing these trends in Canada. Observed warming in Canada is, on average, approximately double the magnitude of global warming (Bush and Lemmen, 2019), with northern parts of the country experiencing the greatest rates of change (*see* Figure 1.1). We are experiencing more extreme heat, less extreme cold, longer growing seasons, shorter snow and ice cover seasons, earlier spring peak streamflow, thinning glaciers, thawing permafrost and rising sea levels (Bush and Lemmen, 2019). Losses from extreme events, such as floods and wildfires, are also increasing. In recent Canadian surveys, 87% of respondents indicated that they are already seeing the effects of climate change in their community (Natural Resources Canada, 2019), and 93% indicated that they believe climate change is either having an impact on their health now or will in the future (Environics Research Group, 2017).

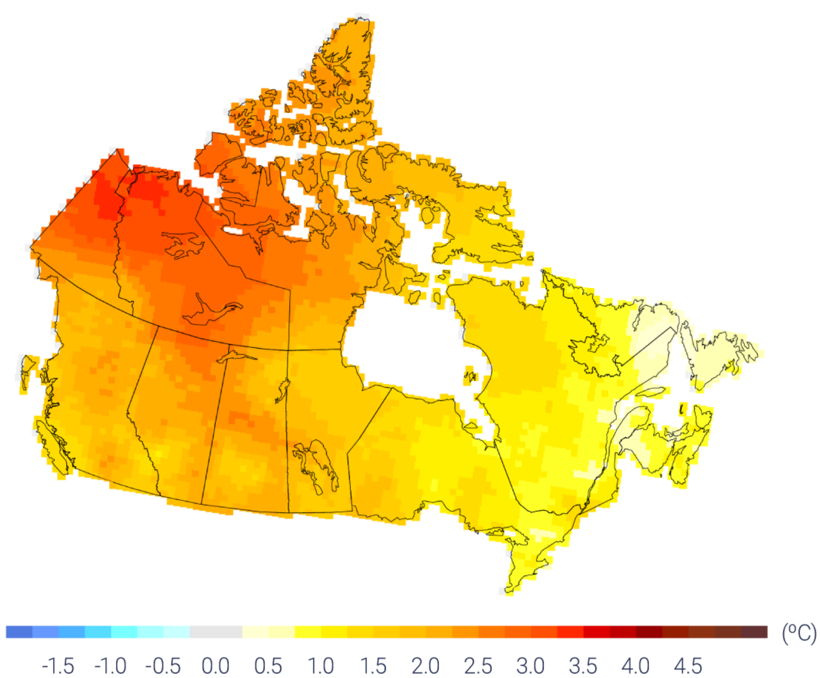

Figure 1.1: Map showing observed changes in annual temperature (°C) across Canada between 1948 and 2016. Source: Zhang et al., 2019.

These observed trends and documented impacts have firmly established the scientific basis for climate change. Debates over whether climate change is real have largely been replaced by discussions on how to respond. The need to plan for and to address climate change impacts grows daily. Decisions taken now to address climate change impacts will have important ongoing implications for Canada's society, economy and environment. However, while there is clearly an urgent need to take action on climate change (IPCC, 2018), the path forward can be complicated. Climate change is a global issue with widespread, pervasive, interacting and often complex impacts occurring at all scales. At a basic level, there are two critically important response pathways—mitigation (greenhouse gas (GHG) emissions reduction) and adaptation—which are related and co-dependent (*see* Box 1.1).

Box 1.1: Linkages between climate change adaptation and mitigation

There are important linkages between actions that reduce greenhouse gas (GHG) emissions (climate change mitigation) and actions that build resilience to deal with climate change impacts (adaptation). As [Canada's Changing Climate Report](#) concluded, "the rate and magnitude of climate change under high versus low emission scenarios project two very different futures for Canada" (*see* Figure 1.2).The ultimate success of adaptation in Canada will be influenced by which GHG emissions pathway the world ultimately follows.

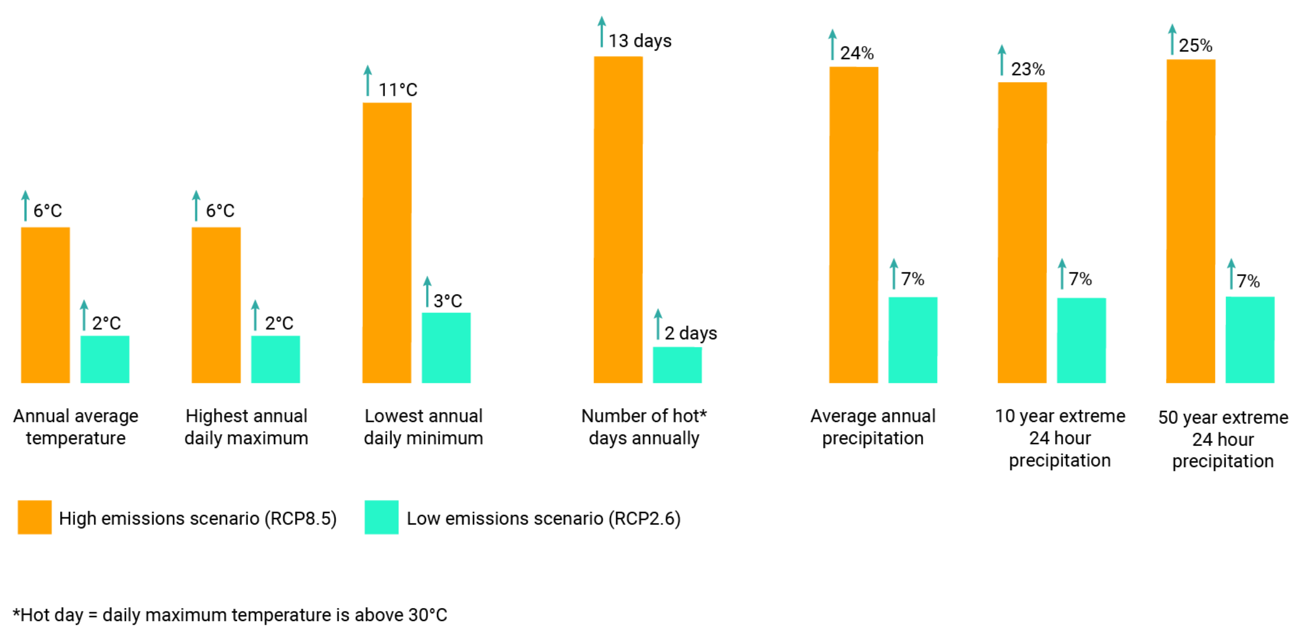

Figure 1.2: The differences between projections for climate variables under high and low emissions scenarios reveal two different potential futures for Canada. The high emissions scenario (RCP8.5) is associated with an

increase in global average temperature of about 3.7 °C by the late century, relative to the 1986–2005 reference period, whereas the low emissions scenario (RCP2.6) is associated with a global average temperature of about 1.0 °C for that same time period. Source: Adapted from Government of Canada, 2019.

As warming increases, climate-related risks and impacts also increase (IPCC, 2018). Higher rates and amounts of warming make it more difficult for adaptation actions to offer sufficient protection against these impacts. This means that significant impacts would remain even after adaptation measures are implemented, and that the chances of reaching limits to adaptation are more likely (Klein et al., 2014). Adaptation limits are reached when there are no longer any practical or feasible adaptation options available, meaning that intolerable risks must be accepted, adaptation objectives must be abandoned and/or transformation and last-resort measures, such as relocation or retreat, must take place (Dow et al., 2013).

Interactions between adaptation and mitigation decisions are illustrated in Figure 1.3. Co-benefits and synergies can be obtained for actions that have both adaptation and mitigation objectives (top right panel)—these are referred to as sustainable "win-win" approaches. For example, the use of nature-based approaches to adaptation in cities creates urban environments that are more resilient to heat waves (reducing associated health impacts) and to intense rainfall (reducing associated flooding), while also sequestering carbon and reducing energy demand (*see* Cities and Towns chapter). The top-left and bottom-right panels identify risk trade-offs that can emerge from particular actions that are designed to meet only one objective (adaptation or mitigation), but that can adversely affect the other objective. For instance, certain adaptation decisions can result in an increase in GHG emissions (e.g., the increased use of air conditioners during heat events); similarly, certain mitigation choices increase local vulnerability or risk (e.g., the increased exposure of the electricity grid to water supply shortages, which could result from expanded use of hydro-electricity). Priority should be given to minimizing or avoiding these negative consequences when planning actions to respond to climate change.

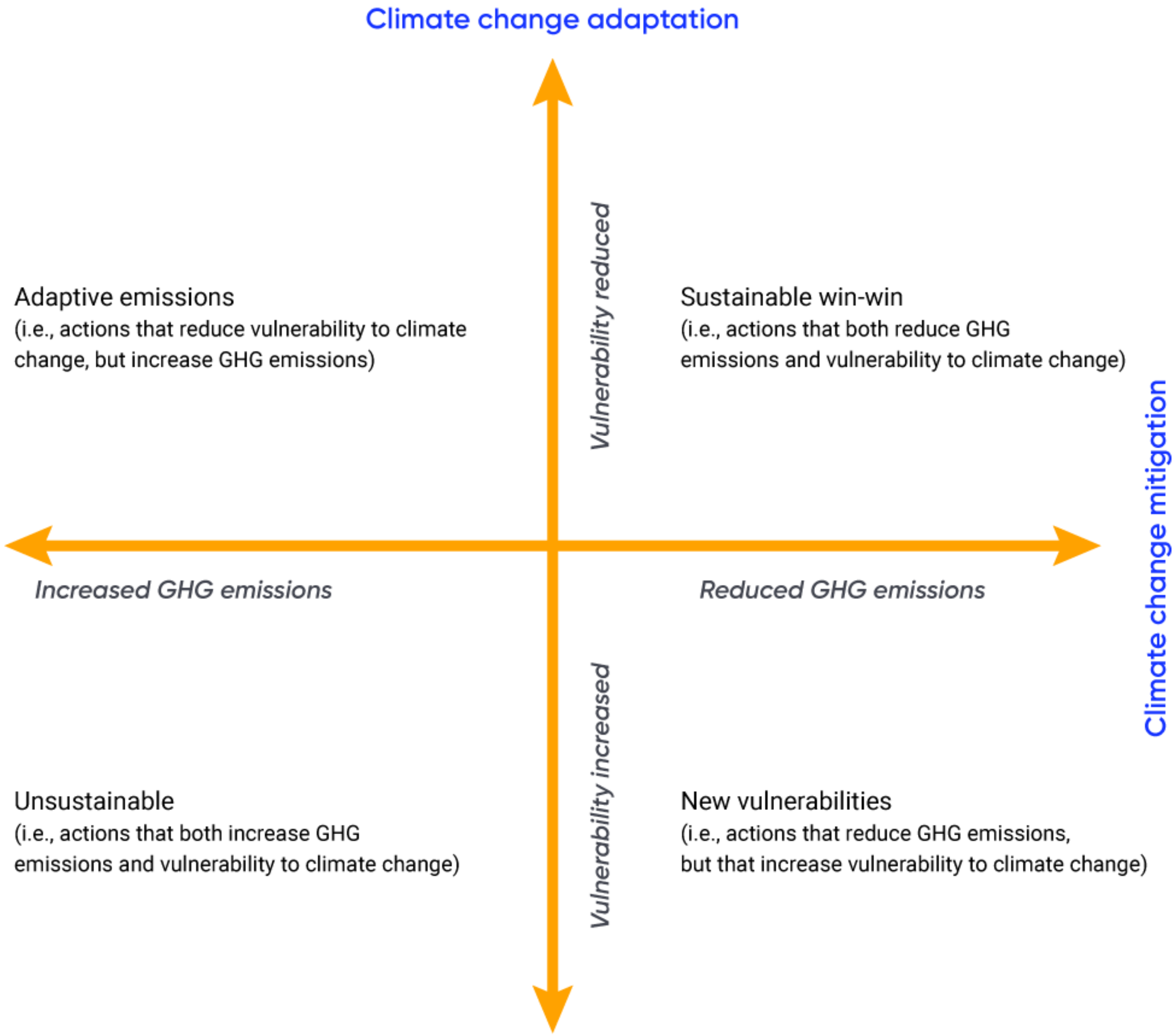

Figure 1.3: Examples of trade-offs and co-benefits of actions where there are linkages between climate change adaptation and mitigation. Source: Adapted from Jones et al., 2014.

This report focuses on climate change adaptation—actions that reduce the negative impacts of climate change or that take advantage of potential new opportunities. Adaptation builds resilience and reduces risk related to current and future climate change impacts. It involves adjusting plans, policies and actions, and can be reactive (i.e., occurring in response to climate change impacts) or anticipatory (i.e., occurring before impacts of climate change are observed). As a concept, adaptation is straightforward; in practice, however, it can range from being simple to incredibly complex. Our understanding of the ways in which climate change affects vulnerable groups and segments of the population is continuing to develop, highlighting the important socioeconomic and equity dimensions of adaptation decisions. Adaptation also offers the opportunity to generate significant co-benefits, such that investments to address climate change impacts in one particular sector or area can result in benefits elsewhere. Similarly, unintended consequences can result if planning and decisions do not adequately consider the broad system and context in which the decisions are being made.

To help address complexities and promote action on climate change adaptation, decision makers need access to reliable information. Knowledge assessments on climate change impacts and adaptation address this need by providing decision makers with the foundation necessary for making evidence-based decisions. Such assessments synthesize existing knowledge on the key issues by following a rigorous process that ensures the end products are credible, relevant and useful to decision makers. While being policy-relevant and structured to inform decisions, assessments are not policy-prescriptive, nor do they provide specific instructions or recommendations. Assessments can be carried out at different scales—from the international assessments of the IPCC to national, regional and local-scale initiatives. Knowledge assessments differ from risk assessments, which apply analytical methods to estimate the probability and consequence of risks associated with current and future climate change impacts. However, risk assessments can both inform and be informed by knowledge assessments. Recent examples of risk assessments in Canada include those at the national scale (e.g., CCA, 2019) and regional scale (e.g., Ministry of Environment and Climate Change Strategy, 2019).

1.2 Canada's National Knowledge Assessment process

Canada in a Changing Climate: Advancing our Knowledge for Action is Canada's national-scale knowledge assessment process. Launched in 2017, it builds upon past assessments of climate change impacts and adaptation led by the Government of Canada, which examined key issues for Canada from regional perspectives (Lemmen et al., 2016; Lemmen et al., 2008) and sectoral perspectives (Palko and Lemmen, 2017; Warren and Lemmen, 2014; Seguin, 2008). The current National Knowledge Assessment process is producing a series of reports that assess how and why Canada's climate is changing; the impacts of these changes on our communities, environment and economy; and how we are adapting (*see* Box 1.2). The resulting reports are resources for Canadians, raising awareness of the issues facing our country and providing information to support evidence-based decisions and actions for addressing climate change and adapting to its impacts. The *National Issues Report* is the second full report to be released in the current assessment series, following the release of *Canada's Changing Climate Report* in 2019.

Box 1.2: Overview of the products included in the 2016–2021 National Knowledge Assessment process

A total of five assessment reports will be released within the current National Knowledge Assessment process (2016–2022), over the course of three phases (*see* Figure 1.4). The first report in the series, *Canada's Changing Climate Report* (2019), provides the climate science foundation, assessing how and why Canada's climate has changed and what changes are projected for the future. The focus of the subsequent reports is on how these changes are affecting the country now and in the future; our vulnerability to climate change impacts; and the role of adaptation in reducing risks and building resilience. To reach broader audiences, the process is supported by an interactive website (changingclimate.ca), and a series of targeted supplementary products are being developed. Enhanced engagement has been a priority throughout the process. Starting with the scoping meeting in 2016, opportunities were made available for the public and experts to provide input on the current assessment, including through workshops, conference sessions, surveys and online.

See the FAQs for additional information about the current National Knowledge Assessment process.

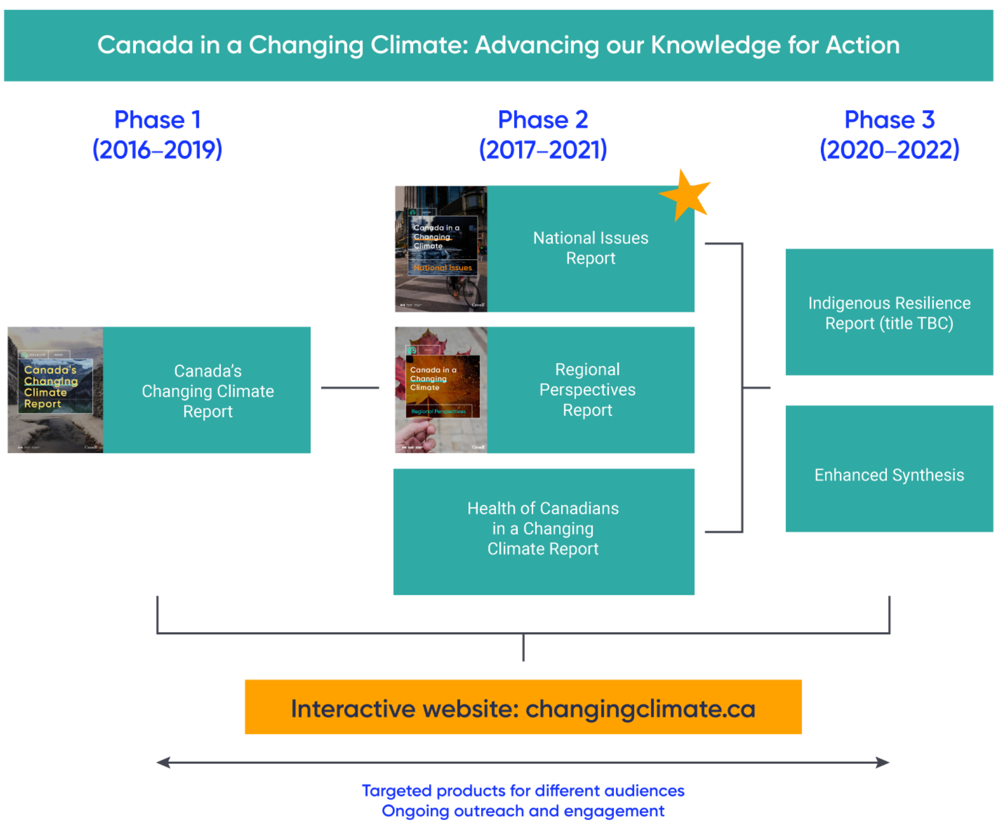

Figure 1.4: Reports developed under the current National Knowledge Assessment process (2016–2022), *Canada in a Changing Climate: Advancing our Knowledge for Action*.

1.3 Scope and structure of the *National Issues Report*

The *National Issues Report* provides a nation-wide perspective on how climate change is impacting our communities, environment and economy, and how we are adapting to reduce risks. The report focuses on themes of national importance that benefit from an integrated, pan-Canadian perspective. It is intended to support evidence-based decisions, and to help decision makers learn from examples of adaptation in practice and to take action on adaptation. In addition to the Introduction, the report includes the following eight chapters:

- Cities and Towns;
- Rural and Remote Communities;
- Water Resources;
- Ecosystem Services;
- Costs and Benefits of Climate Change Impacts and Adaptation;
- Sector Impacts and Adaptation;
- Climate Disclosure, Litigation and Finance; and
- International Dimensions.

Together, these chapters present a clear picture of how climate change is currently affecting and will affect Canada's society, environment and economy. The report reinforces the conclusions of past assessments, which found that impacts of climate change are being felt by all sectors across the country, and that impacts are often cumulative, cross-sectoral, and increasing in frequency and magnitude. Each chapter discusses key vulnerabilities, risks and challenges, new and innovative approaches to adaptation, and also identifies knowledge gaps and emerging issues to help establish a baseline and inform future work. Case stories are featured throughout the report to showcase examples of adaptation from across the country, and to allow diverse voices to be heard.

The content of each chapter is structured around **key messages**—high-level statements that provide an overview of the key issues facing the region or sector, and that reflect the state of knowledge on climate change impacts and adaptation. This approach allowed the chapters to go into greater depth on issues of priority to stakeholders and partners, as identified through engagement and outreach activities, rather than assessing all relevant issues pertaining to a given topic or region. Each chapter contains five to eight key messages, each of which is supported by a plain language summary.

The report draws from existing knowledge on climate change impacts and adaptation from a wide range of sources, including peer-reviewed literature, broader literature, practitioner perspectives, as well as Indigenous Knowledge and local knowledge. It does not include original research. Enhanced inclusion of Indigenous Knowledge was a priority for the report, and most chapters include a key message on Indigenous Knowledge and/or case stories that focus on Indigenous themes related to climate change impacts and adaptation. Due to production timelines, it was necessary to include cut-off dates for incorporating new knowledge sources;

as such, the chapters may not reference the newest available literature or knowledge on a given topic. The assessment content was also finalized before the learnings from the COVID-19 pandemic emerged and therefore does not address the impacts of the pandemic, or any potential relationships between climate change and COVID-19.

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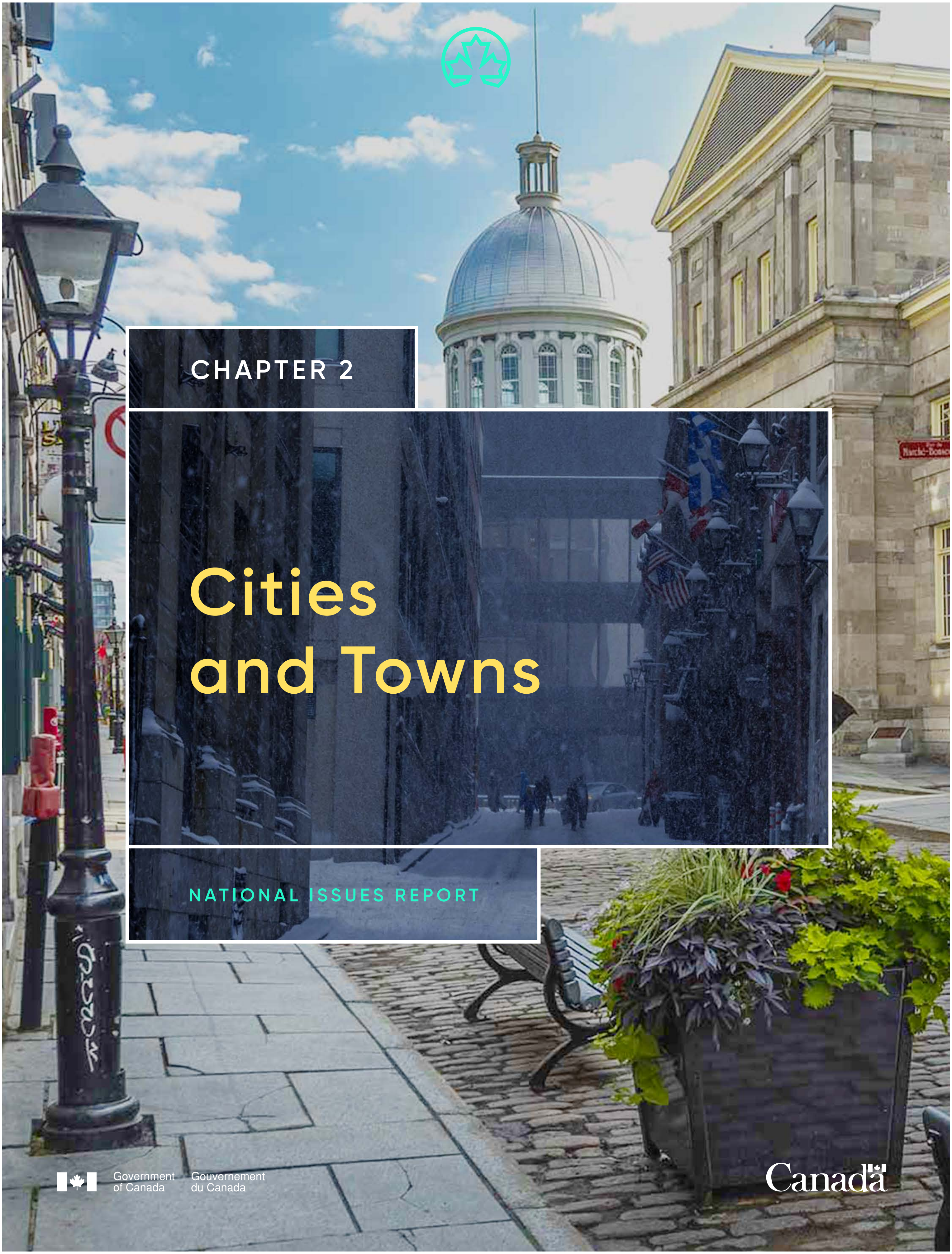

CHAPTER 2

Cities and Towns

NATIONAL ISSUES REPORT

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Canada

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Key messages

Climate change is threatening Canada's ageing infrastructure (*see* Section 2.2)

Safe and reliable infrastructure and resilient buildings are essential to life in cities and towns. The projected changes in climate will increase risk for Canada's ageing infrastructure, causing structural damage, compromising system reliability and threatening health and safety. Integrating climate change information into the design, operation and management of infrastructure projects will help minimize risk.

Enhancing green spaces helps cities and towns adapt to climate change (*see* Section 2.3)

Green infrastructure, such as parks, wetlands and green roofs, in Canada's cities and towns increase the quality of life for residents and improve climate resilience. Recognizing the value of the benefits associated with green infrastructure and nature-based adaptation solutions will be useful in advancing their use to reduce impacts from climate change and other stressors.

Climate change will hit those already struggling in cities and towns the hardest (*see* Section 2.4)

Climate change will impact individual and community health and well-being in cities and towns. However, the negative impacts from climate change will not affect all members of society equally. Considering social equity in adaptation decisions will help reduce the vulnerability of those at highest risk and will ensure that benefits are distributed fairly.

Working together yields the most successful outcomes (*see* Section 2.5)

Effective adaptation approaches to climate change consider diverse perspectives and priorities. Local governments are increasingly playing a strong role in driving meaningful collaboration with different groups when it comes to designing, planning and implementing adaptation in their communities.

Indigenous peoples in cities and towns are often affected in unique ways by climate change (*see* Section 2.6)

Canada's cities and towns are home to large populations of Indigenous peoples, who are often affected in unique ways by a changing climate. Attention is being given to Indigenous issues, and the inclusion of Indigenous perspectives and expertise in municipal adaptation planning processes is occurring, but this is not widespread. Strengthening collaboration with Indigenous peoples will require increased capacity and additional research.

Cities and towns are moving from adaptation planning to implementation (*see* Section 2.7)

Implementation of adaptation initiatives by cities and towns is not keeping pace with the risks posed by current weather extremes and future climate changes. However, examples of implementation are becoming more common, and the barriers to action are being reduced. Promising practices like mainstreaming and innovative funding arrangements offer opportunities to scale up and accelerate implementation.

Monitoring and evaluation of adaptation is an important and often overlooked step (*see* Section 2.8)

Monitoring and evaluation methods are required to track adaptation progress, and measure whether adaptation efforts are resulting in their desired outcomes. While promising approaches exist, monitoring and evaluation of adaptation projects and outcomes are still rare, and there is value in helping cities and towns to develop approaches that are effective and comprehensive.

2.1 Introduction

2.1.1 Cities and towns

Over 80% of Canadians live in urban areas (*see* Box 2.1; Statistics Canada, 2017a), and more than half (51.8%) of Canada's Indigenous population lives in a metropolitan area of at least 30,000 people (Statistics Canada, 2017b). Our cities and towns help drive the national economy, and provide resources and opportunities that contribute to individual and community health and well-being. Although cities and towns have many attributes that increase their adaptive capacity (Natural Resources Canada, 2016); concentrated populations, exposure of economically-valuable assets, ageing infrastructure, degraded ecosystems and social inequality can make urban areas and their residents highly vulnerable to climate change (*see* Figure 2.1; Maxwell et al., 2018).

Figure 2.1: Assets and challenges that influence adaptive capacity in cities and towns.

Changes in Canada's climate are already evident and projected to continue. For example, parts of the country have experienced higher temperatures, more extreme heat, less extreme cold, shorter snow and ice cover seasons, earlier spring peak streamflow, and rising sea level (Bush and Lemmen, 2019). In addition, increased precipitation is projected for most of Canada, on average, although summer rainfall may decrease in some areas. More intense rainfalls will increase urban flood risks, while in coastal regions, sea-level rise and more extreme high-water events will increase the risk of coastal flooding in some communities (Bush and Lemmen, 2019). These changes will result in greater impacts on cities in the future, unless appropriate adaptation and risk management are implemented (*see* Table 2.1).

Managing climate risks is essential, and can provide a range of direct and indirect economic, individual, social and environmental benefits. Cities and towns can also adapt to take advantage of opportunities that a changing climate will bring, such as decreased heating demand in buildings (Amec Foster Wheeler and Credit Valley Conservation, 2017). Reducing net greenhouse gas emissions (mitigation) is essential to managing future risks (Bush and Lemmen, 2019), although a discussion of mitigation efforts is largely outside of the scope of this report, which focuses on climate change impacts and adaptation.

Population growth, urbanization, densification and increased resource consumption in the coming decades will amplify the sensitivity of cities and towns to climate-sensitive hazards (Webb et al., 2018). For example, the population in Ontario's Greater Golden Horseshoe is expected to grow by 50%, reaching 13.5 million people by 2041 (Government of Ontario, 2017), and that of Metro Vancouver is expected to increase by 25% to 3.2 million people over the same time period (Metro Vancouver, 2014, 2018). This population growth will mean higher exposure to impacts (as more people would be affected), along with greater demand on critical systems like energy, water and health care. The composition of Canada's population can also affect vulnerability; for instance, newcomers to Canada and the elderly can have higher vulnerability to extreme weather events (Chang et al., 2015).

This chapter assesses climate change impacts and adaptation in cities and towns across Canada and acknowledges that each location experiences and adapts to climate change differently (Hunt and Watkiss, 2011). This chapter references Canadian and international literature, and includes case stories that provide practical examples of adaptation in action. The content has been structured using key messages that reflect the current state of research and practice on issues of priority to cities and towns. The volume in which this chapter appears is part of a suite of complementary products that are contributions to the national assessment process Canada in a Changing Climate: Advancing our Knowledge for Action.

Box 2.1: Urban areas

Although the term "urban area" is often used interchangeably with cities and towns, Statistics Canada has replaced the term "urban area" with "population centre" and uses the following discrete categories: small (populations between 1,000 and 29,999), medium (populations between 30,000 and 99,999), and large (populations of 100,000 or more) (Statistics Canada, 2017e). As in previous assessments (e.g., Palko and Lemmen, 2016), this chapter focuses primarily on medium and large population centres, with some consideration of small centres that have more than 10,000 people. It is estimated that 500 of Canada's 3,650 cities and towns have populations over 10,000. For discussion on climate change impacts and adaptation in communities smaller than 10,000 people, see the Rural and Remote Communities chapter.

2.1.2 Climate change impacts in cities and towns

As the global mean temperature continues to increase, cities and towns across Canada will experience warmer temperatures, shifting precipitation patterns (e.g., less snow and more rain, sustained periods of drought), increased frequency and intensity of some extreme weather events, and—for most coastal cities—sea-level rise (Bush and Lemmen, 2019). Under all emissions scenarios of the Intergovernmental Panel on Climate Change (IPCC), these changes will result in an increased incidence of acute and chronic biophysical impacts, including more frequent and intense heat events (*see* Figure 2.2), increased incidences of poor air quality (e.g., from ground-level ozone, particulate matter), short-duration, high-intensity rainfall events, wind storms, wildland-urban interface fires, increased coastal erosion, storm surge flooding and decreased water quality (Bush and Lemmen, 2019; Field, 2018; BC Ministry of Environment and Climate Change Strategy, 2017; Government of Canada, 2016; Gasper et al., 2011). These biophysical impacts will affect built infrastructure, natural environments, individuals and communities (*see* Table 2.1). Such impacts are accentuated in developed areas because many impact-reducing natural surfaces have been replaced by water-shedding, heat-absorbing and re-radiating surfaces, and the population density is higher (Seto and Shepherd, 2009; Venema and Temmer, 2017). Many of the high costs associated with these impacts (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter) will be borne by local governments.

Table 2.1: Common climate change impacts facing cities and towns

CATEGORY	COMMON CLIMATE CHANGE IMPACTS
Infrastructure and buildings	• Damage to infrastructure and buildings from storms • Increased cooling demand and decreased heating demand in buildings • Potential increase in disruption to and failure of electrical systems from heat and storms • Increased winter maintenance costs and higher public safety risks • Damage to coastal infrastructure due to sea-level rise
Natural systems	• Shifts in distributions of plant and animal species, including beneficial and invasive species • Degradation of urban ecosystems and those in the outskirts • Increase in environmental pollution (e.g., rainfall events transporting contaminants into waterways) • Saltwater intrusion into water supply aquifers
Individuals and communities	• Increased social inequity • Business disruptions • Mental and physical health impacts • Loss of cultural landmarks, heritage and traditional practices • Changes to recreation and tourism opportunities

Sources: Abbott and Chapman, 2018; Cedeño Laurent et al., 2018; Field, 2018; Diamond Head Consulting Inc., 2017a; Public Health Agency of Canada, 2017; Government of Canada, 2016; Giordano et al., 2014; Revi et al., 2014; Solecki and Marcotullio, 2013; Gasper et al., 2011.

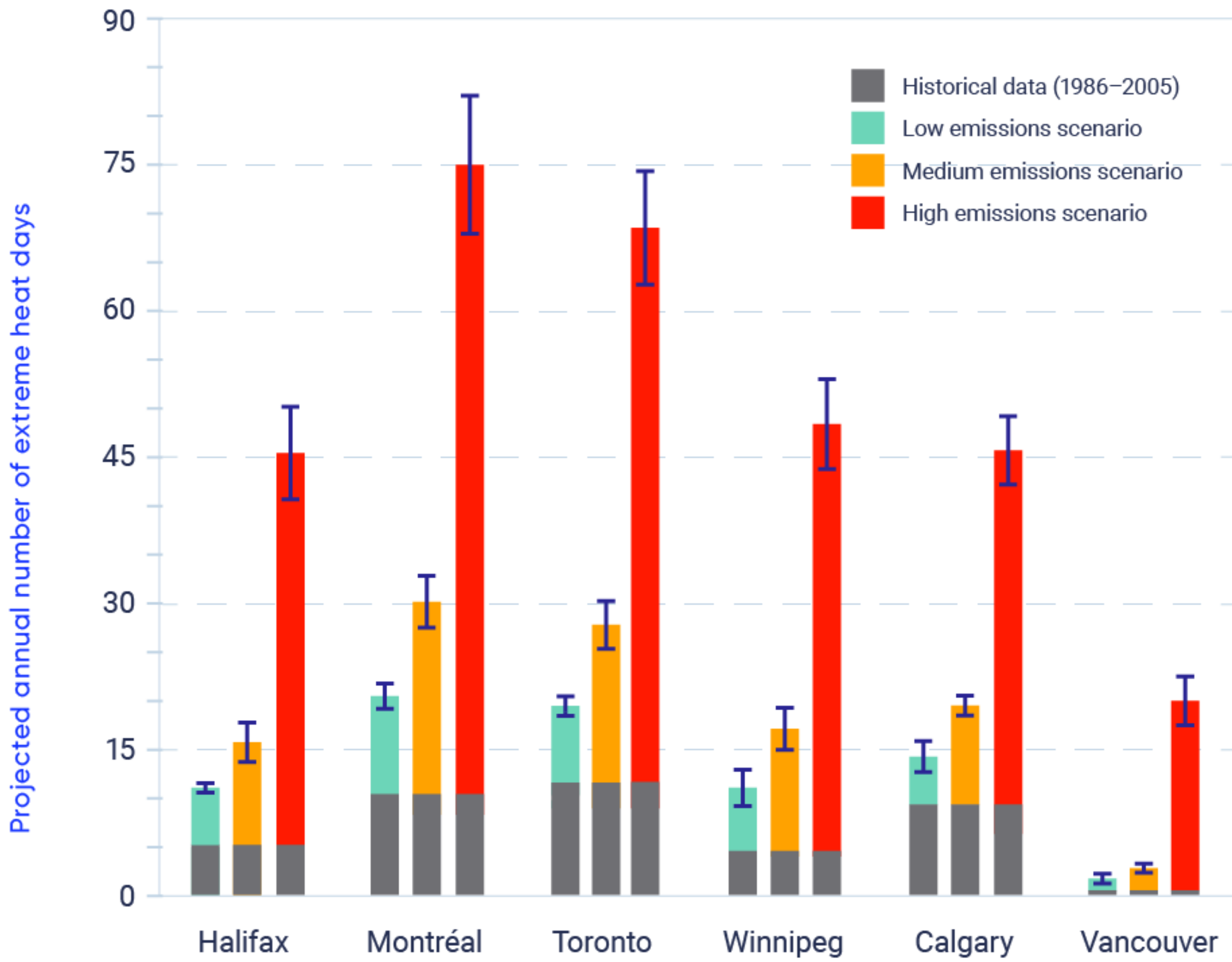


Figure 2.2: The annual number of extreme heat days projected for six Canadian cities under three warming scenarios: global mean surface temperature of 1.5°C, 2°C, and 4°C above pre-industrial levels. The values are based on statistically downscaled simulations by 24 climate models participating in CMIP5, with the error bars representing the 25th and 75th percentiles, and the grey section showing the number of historical extreme heat days (1986–2005). The threshold for extreme heat differs by city (e.g., Toronto = 31°C, Vancouver = 29°C). Data source: Environment and Climate Change Canada.

2.2 Climate change is threatening Canada's ageing infrastructure

Safe and reliable infrastructure and resilient buildings are essential to life in cities and towns. The projected changes in climate will increase risk for Canada's ageing infrastructure, causing structural damage, compromising system reliability and threatening health and safety. Integrating climate change information into the design, operation and management of infrastructure projects will help minimize risk.

Historical and recent exposures to weather extremes have shown that urban infrastructure is vulnerable to these types of events. Climate change will increase the risk of overheated buildings, damaged infrastructure (e.g., bridges during flooding) and power outages across Canada. Increasing the resiliency of Canada's ageing infrastructure is challenging due to factors such as higher levels of use beyond initial design, the large investments required, and performance under uncertain future climate conditions. In addition, infrastructure design to date reflects an assumption of a steady-state climate, whereas we now must design for "non-stationarity" in order to minimize disturbance and damage as the climate continues to change dynamically. Infrastructure was identified as the top sector at risk to climate impacts, but also has the greatest "adaptation potential" to avoid and reduce negative consequences, as long as careful planning is undertaken (Council of Canadian Academies, 2019). The state of research and practice in Canada is advancing, as are the resources available to cities to towns.

2.2.1 Introduction

The infrastructure in cities and towns includes water systems (e.g., stormwater, wastewater, drinking water), transportation systems, public and private buildings, sport and recreation facilities, utilities (e.g., electricity and gas), telecommunications and industrial sites (*see* Box 2.2 for more details). Nearly two thirds of core public infrastructure is owned and maintained by municipal governments, and over one third is in need of retrofit or replacement due to being in a relatively poor condition (Project Steering Committee, 2016). Rising temperatures, changing hydrological conditions and more frequent extreme weather events will increase the risk of failure and make it more difficult to deliver optimal levels of service across the entire lifespan of existing and new infrastructure assets (Asset Management BC, 2018; Amec Foster Wheeler and Credit Valley Conservation, 2017).

Box 2.2: Infrastructure

The term “infrastructure” can mean many different things. Public Safety Canada provides a list of ten sectors that are termed critical infrastructure: health, food, finance, water, information and communication technology (ICT), safety, energy and utilities, manufacturing, government, and transportation (of all types—ground, air and water) (Public Safety Canada, 2020). The emphasis of this chapter is on the physical assets that underpin the functioning of these and other sectors within cities and towns, including buildings. Much of the infrastructure in population centres is publicly owned, such as roads, water mains and public buildings. Other infrastructure, such as most buildings, and ICT, natural gas and power distribution can be privately owned (in some cases depending on the regulatory structure). Infrastructure assets are dependent on other assets and services from other infrastructure. The term “interdependent” is used to describe cases where assets or systems are dependent on each other.

2.2.2 Approaches and mechanisms to reduce risks

The Climate-Safe Infrastructure Working Group—a panel of scientists, registered engineers and architects in California—defines climate-safe infrastructure as “infrastructure that is sustainable, adaptive and that meets design criteria that aim for resilience in the face of shocks and stresses caused by the current and future climate” (Climate-Safe Infrastructure Working Group, 2018, p. 5). Although this goal is conceptually straightforward, there are many challenges in achieving it (e.g., Climate-Safe Infrastructure Working Group, 2018; Amec Foster Wheeler and Credit Valley Conservation, 2017). As the field of climate change adaptation matures, approaches are emerging to assist infrastructure designers and operators as they modify their planning and design approaches. The Infrastructure and Buildings Working Group—a multi-stakeholder working group under Canada’s Climate Change Adaptation Platform—outlines the key areas that must be addressed, several of which are presented below:

- Development of guidelines, codes, standards and specifications that take into consideration the expected climate change impacts;
- Development of critical infrastructure inventories, including the evaluation of vulnerabilities and identification of priority at-risk areas, based on the projected impact of climate change;
- Identification of high-risk areas based on recent events (e.g., new flood zone mapping);
- Completion of risk assessments and cost benefit analyses of alternatives to support decision-making on priority adaptation actions; and
- Integration of planning and decision-making between departments within an organization or between stakeholders (Amec Foster Wheeler and Credit Valley Conservation, 2017).

Although it is difficult to precisely track progress in each of these areas, there is evidence of advances. For example, asset management is a relatively widespread practice that seeks to inventory and manage existing and new infrastructure across municipal corporations, in a way that maximizes benefits and reduces risks, while reflecting the context and priorities of the community (Federation of Canadian Municipalities, 2018). Over the last few years, the asset management community has been encouraged to incorporate climate change into its practices (Asset Management BC, 2018). While the inclusion of climate change is not yet well established, it involves considering how a range of potential climate impacts may affect levels of service, and building these considerations into asset management activities (*see* Case Story 2.1; Federation of Canadian Municipalities, 2018). This process can also be used to manage natural assets (e.g., wetlands), although this practice is still very new (Municipal Natural Assets Initiative, 2017). Incorporating climate change into asset management represents a significant opportunity to accelerate adaptation through mainstreaming, and to pursue low-carbon options during infrastructure renewal (Adaptation to Climate Change Team, 2019).

Codes, standards and guidelines are essential drivers of climate-safe infrastructure that are largely determined by various levels of government (Amec Foster Wheeler and Credit Valley Conservation, 2017). For example, in Quebec, standard BNQ 3019-190 provides information, guidelines and recommendations to improve the thermal performance of parking areas (e.g., reduced surface area, increased greenspace, permeable pavement) with the goal of reducing the urban heat island effect (Bureau de normalisation du Québec, 2013). The Borough of Rosemont–La Petite-Patrie, Quebec, has used this standard to require that “paving material in all new parking, loading and storage areas must meet a minimum solar reflectivity index rating of 29” (Government of Canada, 2011, p. 2). The Standards Council of Canada (2019) is also advancing work in this area , including a new national guideline on basement flood protection (Canadian Standards Association, 2018) and support for a Canadian standard for flood-resilient communities (Moudrak and Feltmate, 2019). Additional information on buildings is provided in Box 2.3.

2.2.3 Decision-support tools

Despite promising examples, designing for an increasingly non-stationary climate remains a challenge with evolving solutions. Designers are encouraged to incorporate flexibility to allow for uncertainty (Field, 2018; Milly et al., 2008), and to use safe-to-fail approaches that minimize consequences instead of the probability of failure (Climate-Safe Infrastructure Working Group, 2018). Traditionally, infrastructure parameters and thresholds have relied on historical weather data (Amec Foster Wheeler and Credit Valley Conservation, 2017). Given the long lifespans of most infrastructure, future climate projections will be needed to establish parameters and thresholds for infrastructure. Intensity Duration Frequency (IDF) curves relate rainfall intensity with its duration and frequency of occurrence, and are often used to inform infrastructure decisions. Tools such as the IDF CC Tool 4.0 (Simonovic et al., 2018) can be used to develop IDF curves based on historical data, as well as under future climate conditions, thereby helping to incorporate climate considerations into infrastructure decisions. For instance, IDF curves were used in a study of Saskatoon residential retention ponds under future climate scenarios (Elshorbagy et al., 2018).

The Climate Lens from Infrastructure Canada represents an effort to embed the consideration of climate risk in professional practice. It requires analysis of climate change resilience during the planning and design phases of a project, as a prerequisite to funding for projects over $10 million, and also requires consideration of how the emissions from all projects will be managed and minimized (Infrastructure Canada, 2019). The guide contains a collection of supporting resources, including regional climate resources, engineering data sets (e.g., IDF files), provincial and territorial flood maps, risk assessment methodologies, previous federal assessment reports, and adaptation resources (Infrastructure Canada, 2019).

Professional associations across Canada are increasingly providing voluntary training to their members on the planning and management of climate-safe infrastructure. For example, Engineers and Geoscientists British Columbia has an extensive climate change information portal that aims to support its members as they incorporate climate risk management into their practices (Engineers and Geoscientists British Columbia, 2020). Similarly, the Canadian Society of Landscape Architects has produced a set of adaptation primers to guide its members' practice (Canadian Society of Landscape Architects, 2018), and the Canadian Institute of Planners has a climate change portal with resources to inform planning and design for climate change adaptation, and a new policy for climate change planning that guides professional practice (Canadian Institute of Planners, 2018).

In addition to these decision-support tools, there is also an expanding body of examples and design strategies in the following areas: storm and sanitary sewer design (Moudrak and Feltmate, 2017; Crowe, 2014), transportation infrastructure (Temmer and Venema, 2018; Simonovic et al., 2016; Dennis Consultants, 2008), energy distribution (Gomez and Anjos, 2017; AECOM and Risk Sciences International, 2015; Boggess et al., 2014), water systems (United States Environmental Protection Agency, 2014; Loftus, 2011), and information and communications technology (Kwasinski, 2016).

2.2.4 Funding

Although there are many barriers relating to financing of climate-safe infrastructure in Canada's cities and towns (Amec Foster Wheeler and Credit Valley Conservation, 2017), there are innovative paths forward that are currently available to infrastructure owners and operators. These include incentive-based tools such as local improvement charges (LICs), density for benefit agreements, development costs charges and natural area tax exemptions (Zerbe, 2019; Adaptation to Climate Change Team, 2015). Funding options have also been assessed for natural assets initiatives (Cairns et al., 2019), and municipalities have received funding for adaptation through federally funded programs, such as the Municipalities for Climate Innovation Program (delivered by the Federation of Canadian Municipalities) and the Natural Disaster Mitigation Program (delivered by Public Safety Canada). However, most of these funding opportunities are time-bound, and the amount of funding available generally falls short in comparison to the scale of adaptation responses that are needed. Since public funding sources represent only one quarter of capital expenditures in Canada, it will also be essential to mobilize private investment from businesses, homeowners and public-private partnerships in order to implement adequate infrastructure adaptation (Adaptation to Climate Change Team, 2015).

Box 2.3: Buildings

In the past five years, there has been an increased effort to design for climate resilience at the building level (e.g., BC Housing, 2019). For each building type, there are a number of structural and operational adaptation options available depending on the hazard faced (*see* Figure 2.3). These include general guidance for designers and operators (e.g., BOMA Canada, 2019; Kesik and O'Brien, 2017; City of Toronto, 2016) and also certification systems like BOMA BEST 3.0 (BOMA Canada, 2020) for existing buildings, and the pilot credits in the RELi project rating system for new buildings (Pierce, 2017). There are also a number of pilot projects. For example, the City of Windsor, Ontario, retrofitted a 100-year-old home in the city's core to reduce the risk of flooding by using a variety of property-level flood protection measures, including a backwater valve, sump pump with overflow, and regrading (City of Windsor, 2019).

Enhancing climate resilience through building codes is another approach being used in cities and towns. Many local jurisdictions in Canada have adopted measures to reduce disaster risk through building design, despite limited authority to regulate construction beyond provincial code requirements (City of Barrie, 2017; Town of Wasaga Beach, 2015; City of Cambridge, 2011). For example, most municipalities in Alberta and major cities in Ontario such as Toronto, Ottawa, Windsor, Mississauga and Hamilton have adopted building code interpretations that have resulted in the installation of sewer backflow protection in most new homes to reduce sewer backup risk (Sandink, 2013a). In the City of Victoriaville, QC, the voluntary, incentive-based Habitation Durable [sustainable housing] program includes disaster risk reduction measures, such as improved roof-to-wall connections to reduce wind risk and measures to decrease heat-health risks. Seven additional municipalities in the province of Quebec have adopted Habitation Durable (City of Victoriaville, 2018). Halifax enforces a vertical setback for residential ground floors of all new buildings along its coastline to accommodate sea-level rise, based on predictions and modelling out to the year 2100 (Halifax Regional Municipality, 2014).

For many building-level adaptation measures, there are associated co-benefits. For example, passive solar design in buildings can help maintain comfort, including during power outages, while reducing heating and cooling loads (e.g., via optimized shading). Similarly, foliage and green roofs reduce urban heat, while also retaining stormwater and decreasing cooling demand. These and other building-level resilience measures deliver co-benefits relating to livability and property values as well (Urban Land Institute, 2015).

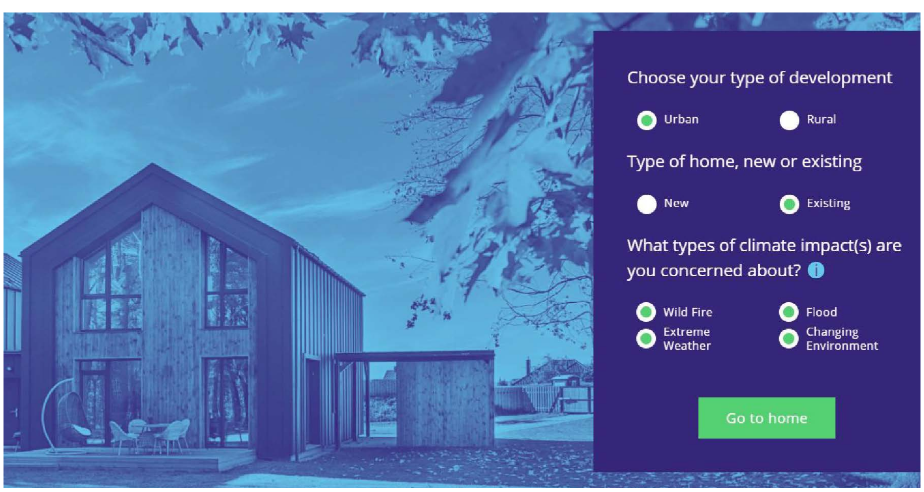


Figure 2.3: A series of screenshots from the website www.climateresilienthome.ca, developed by the City of Edmonton and Ask for a Better World. This interactive tool provides information about modifications for making new and existing homes more climate resilient.

2.2.5 Interdependencies

Creating climate-safe infrastructure requires an operationalized understanding of the interconnected and interdependent nature of urban infrastructure, where interdependency refers to a relationship between two or more infrastructure systems (e.g., electricity distribution and water treatment) (*see* Figure 2.4; Zimmerman and Faris, 2010). Interdependencies can be physical, cyber-based, geographic or operational in nature (C40 Cities and AECOM, 2017), and can lead to cascading impacts across infrastructure systems, involving multiple infrastructure owners (Asset Management BC, 2018). Identifying interdependencies is increasingly considered to be a first step in reducing climate risk (C40 Cities and AECOM, 2017). Pilot projects related to specific assets, including the General Hospital in Nanaimo, BC, are being initiated to explore how interdependencies translate into climate risks (Cross Dependency Initiative, 2019).

Discussions about interdependencies and cascading impacts often highlight the centrality of electricity to urban life. As Figure 2.4 shows, when the electricity supply is disrupted, many negative impacts occur across other infrastructure systems—as well as in natural and social systems (C40 Cities and AECOM, 2017). For example, high-rise buildings may experience disruptions in essential services like water supply and elevator service, and may lose their ability to maintain safe thermal conditions during power outages (Kesik et al., 2019). Buildings tend to be highly interdependent, in that they rely on most other infrastructure types and are designed with minimal ability to function without these infrastructure elements. Utilities across Canada are striving to manage the risks to their distribution networks (e.g., BC Hydro, 2019; Canadian Electricity Association, 2019).

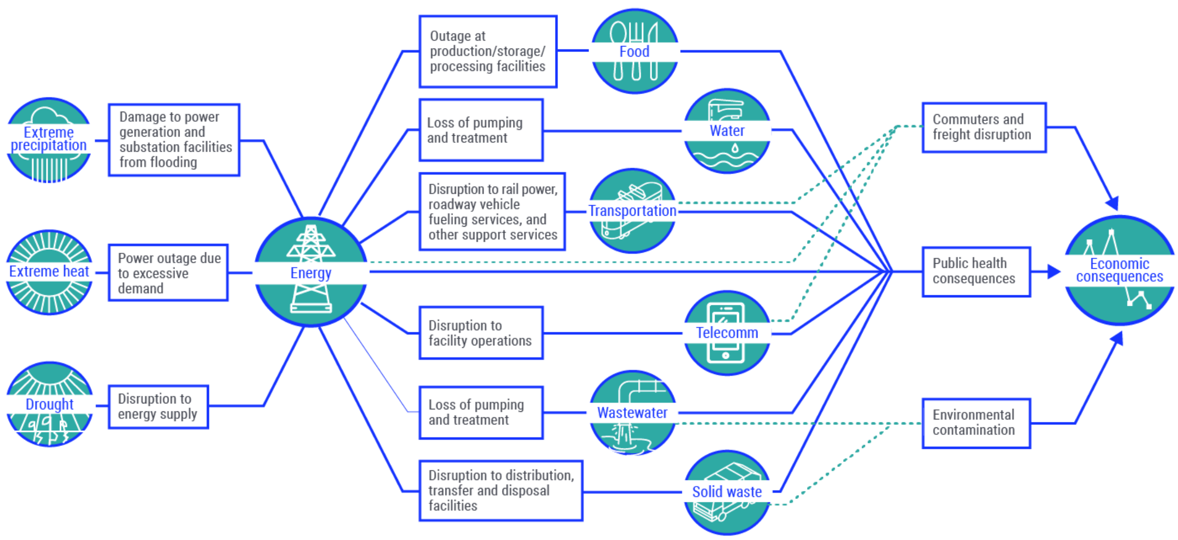


Figure 2.4: A graphical representation of an example of interdependencies between infrastructure systems. Source: Adapted from C40 Cities and AECOM, 2017.

Case Story 2.1: Enhancing infrastructure resilience in Fredericton, NB to reduce flood risk

Located on the Saint John River, the City of Fredericton is the capital of New Brunswick and is home to nearly 60,000 people. The primary climate risk for Fredericton is spring flooding of the Saint John River—a hazard so prominent that a public art piece was commissioned to contextualize the height of floodwaters (*see* Figure 2.5).

Fredericton experienced back-to-back spring floods in 2018 and 2019, both lasting for over a week. For each flood, a significant portion of the arterial transportation network was disrupted, and commuters struggled to travel from one side of the river to the other for work, hospital visits and other activities that are often taken for granted. During this time, the City encouraged using active transportation, free transit, park-and-ride options and telecommuting to ensure business continuity, as well as altering the flow of traffic on the major bridge to permit improved access to and from downtown. Business continuity is one way that City staff have framed adaptation efforts, accepting that eliminating flood risk is not possible.

Persistent flood risk has resulted in over two decades of efforts to ensure that the City's infrastructure is more resilient. Fredericton has relied on a commitment to asset management planning and a long-term vision to guide this work. This has led to changes, such as culverts that are sized 20% above a 1:100 return period; the use of active transportation (e.g., cycling); and rail-corridor trails that have been used as sites for water mains to increase redundancy, and also to act as alternative transportation routes when flooding disrupts vehicle traffic. The City has relied on diverse funding mechanisms to complete this work and will receive support from the National Disaster Mitigation Program to make Fredericton more resilient.

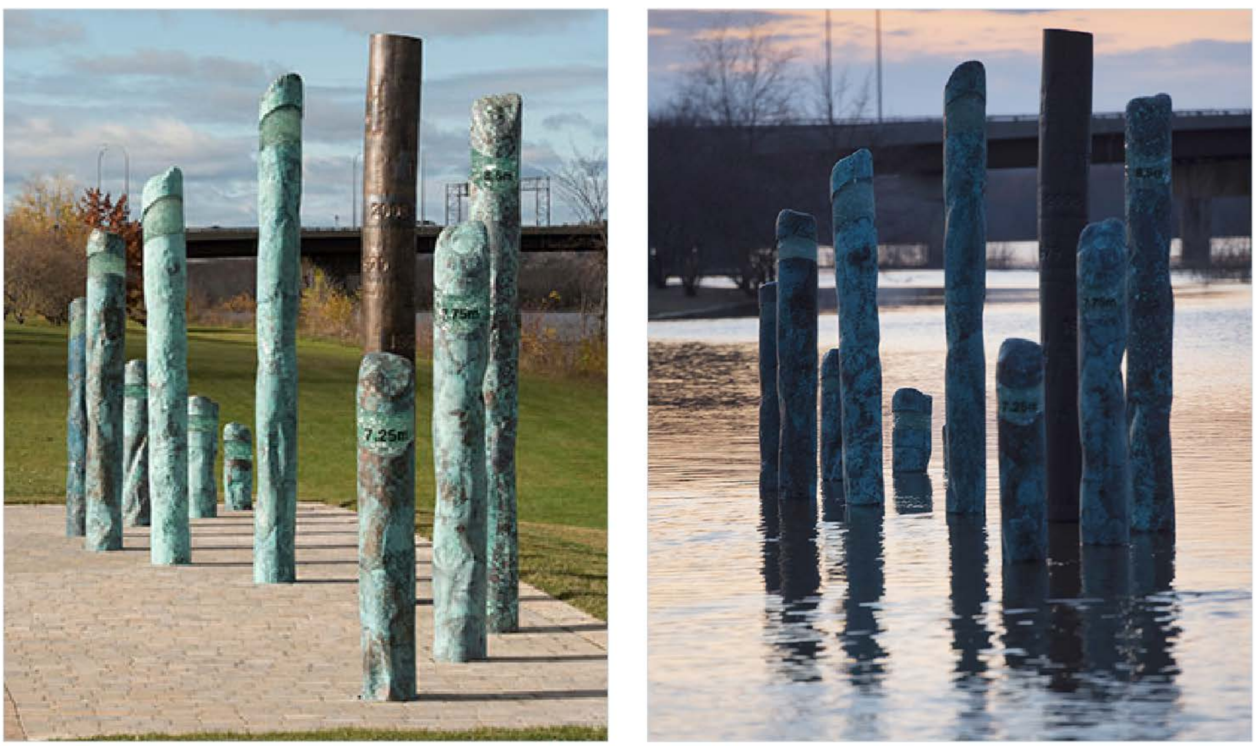


Figure 2.5: Gerald Beaulieu's public art installation "Watermark", consisting of a series of 11 wooden posts of different heights along a riverside walking path in Fredericton, NB. The tallest post—the "memory pole"—is encased in copper sheets that mark the year and peak water level of the Saint John River during the annual freshet. This project is a great example of municipal Public Works collaborating with the Culture Office. Photos courtesy of the City of Fredericton.

2.3 Enhancing green spaces helps cities and towns adapt to climate change

Green infrastructure, such as parks, wetlands and green roofs, in Canada's cities and towns increase the quality of life for residents and improve climate resilience. Recognizing the value of the benefits associated with green infrastructure and nature-based adaptation solutions will be useful in advancing their use to reduce impacts from climate change and other stressors.

The natural environment influences quality of life in Canada's cities and towns, and supports food and water security, as well as providing significant benefits in terms of air quality, water filtration and biodiversity. The ability of green infrastructure to increase resilience to climate change is well understood. Green infrastructure is beginning to be used more widely in Canada's cities and towns, as are innovative approaches to design and governance relating to the natural environment. As the climate changes, protecting and enhancing green infrastructure (see Figure 2.6) will contribute to its resilience and its ability to continue to provide ecosystem services and co-benefits. This requires integration with complementary planning processes (e.g., built infrastructure decisions), as well as consideration of other factors relating to land-use planning and development.

2.3.1 Introduction

Cities and towns incorporate natural systems that include waterways, coastlines, wetlands, urban forests, parks, and remnant ecosystems, as well as built assets such as green roofs, bioswales and rain gardens (*see* Figure 2.6). These natural and engineered assets provide valuable goods and services that can increase adaptive capacity (*see* Ecosystem Services chapter; Frantzeskaki et al., 2019; Adaptation to Climate Change Team, 2017; Kabisch et al., 2017; Terton, 2017) and are often flexible, cost-effective, and broadly applicable in reducing the impacts of climate change (Emilsson and Sang, 2017). Green infrastructure can reduce impacts associated with extreme heat, drought, flooding and sea-level rise, while delivering multiple co-benefits (*see* Table 2.2). For example, there is increasing understanding of the effects that green infrastructure can have on heat and air pollution at the site, neighbourhood and city levels (Zupancic et al., 2015). However, the ability to provide these benefits is threatened by rapid urban growth and development, destructive land and water use practices, and the temperature and precipitation changes and extreme events associated with climate change (The Nature Conservancy, 2018; Emilsson and Sang, 2017; Terton, 2017).

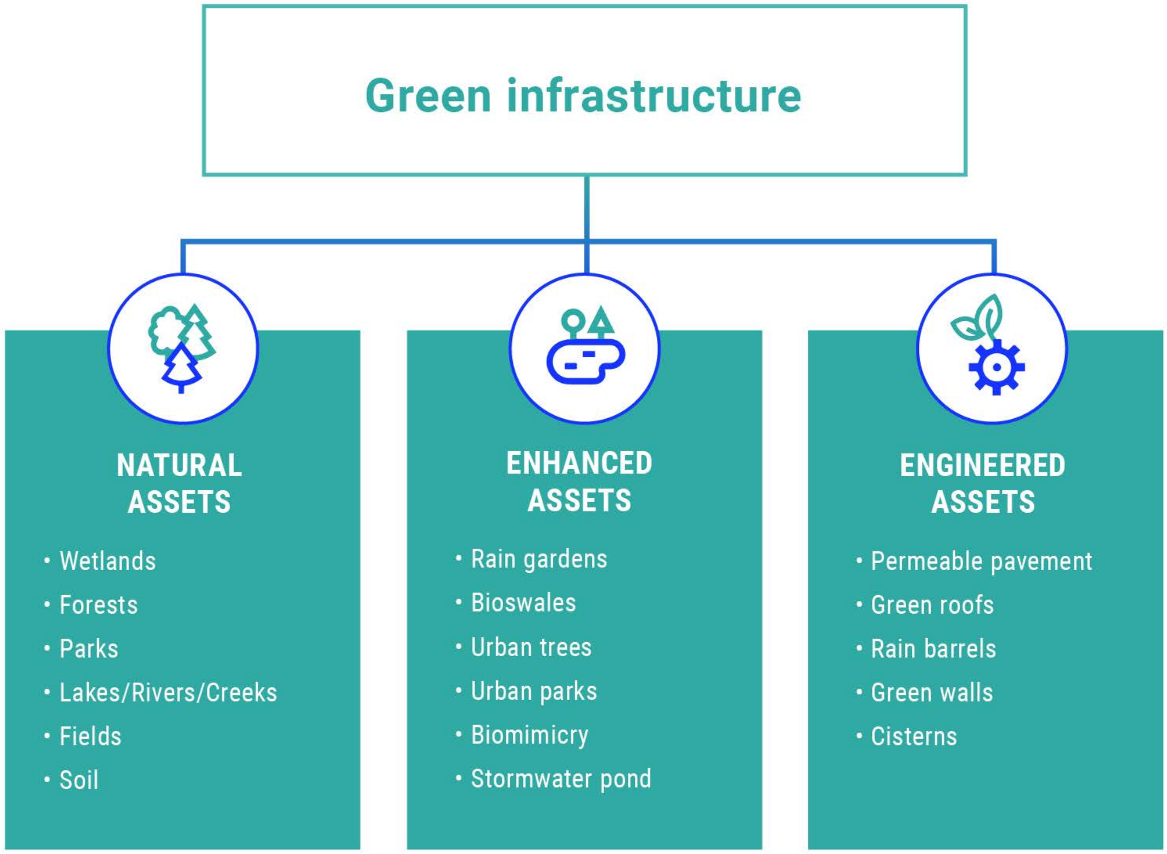


Figure 2.6: Definition of green infrastructure. Source: Adapted from Brooke et. al, 2017.

There is an increasing amount of guidance available for those seeking to use green infrastructure for adaptation (e.g., *see* Case Story 2.2; Terton, 2017). Vulnerability and risk assessment tools also exist. For example, the PIEVC (Public Infrastructure Engineering Vulnerability Committee) protocol was applied to three parks in Mississauga to assess their vulnerability to twelve climate parameters (e.g., flooding, freeze-thaw cycles, drought and air quality). A number of risks were identified that could be managed by construction, operations and management, and/or additional research (Risk Sciences International, 2018).

Table 2.2: Co-benefits of green infrastructure

CATEGORY	CO-BENEFITS
Environmental	• Improved air quality • Improved water availability and quality • Increased habitat and connectivity for biodiversity • Reduced urban temperatures • Erosion prevention • Carbon sequestration and reduced emissions
Social	• Opportunities for recreation and physical activity • Improved mental health • Increased social cohesion (e.g., parks, community gardens, beaches) • Potential for urban agriculture and local food security • Reduced mortality • Educational opportunities • Spiritual value and sense of place
Economic	• Cost effectiveness compared to grey infrastructure • Flood protection • Reduced energy consumption in buildings • Reduced energy required for pumps, etc. • Pollution removal • Improved power transformer capacity and electrical transmission efficiency • Increased property values and property tax revenue

Sources: Arsenijevich, 2018; EPCCARR, 2018; Kabisch et al., 2017; Terton, 2017; Berry, 2016; McDonald et al., 2016; Sörensen et al., 2016; AECOM and Risk Sciences International, 2015; Kardan et al., 2015; Alexander and McDonald, 2014; ARUP, 2014; Beatley and Newman, 2013; Summers et al., 2012; Foster et al., 2011.

2.3.2 Low impact development

Low impact development (LID) aims to return the hydrology of a site as closely as possible to its pre-development conditions (Ahiablame et al., 2013) and is widely recognized as an important strategy for stormwater management in urban areas (Berry, 2016; Dagenais et al., 2014). Examples of LID include green roofs, permeable pavement, rain gardens, bioswales, infiltration planters, vegetated swales, flow-through planters, drywells and retention ponds. These natural assets retain and filter a portion of stormwater, help to recharge water supplies, avoid costly upgrades to hard infrastructure, provide habitat and recreation opportunities, and are viewed as vital components of municipal infrastructure systems (*see* Figure 2.7; Kabisch et al., 2017,). For example, in Washington State's Puget Sound, there is an initiative to install 12,000 rain gardens, which would defer 160 million gallons of water from entering the stormwater system (Stewardship Partners and Washington State University Extension, 2019). Planning is underway for a similar project in North Vancouver (Pacific Water Research Centre, 2020). The City of Niagara Falls now offers a rebate program that will cover 50% of the cost of one rain barrel for its residents (City of Niagara Falls, 2019).

Regulatory approaches have also been effective at increasing LID. For example, Toronto's Green Roof bylaw requires developments with a roof space larger than 2,000 square meters to have green roofs. The City estimates that these green roofing initiatives have alleviated over 9 million litres of stormwater from their drainage systems and mitigated 120 tonnes of greenhouse gas emissions by reducing annual energy usage by 1,000 megawatt hours (Guilbault et al., 2016). LID has been embraced variably, but generally favourably across Canada (Ishaq et al., 2019). Current concerns about LID include lifecycle operational and maintenance requirements, including considerations of maintenance processes and costs, and the impact of freezing rain and winter rain events on the efficiency and survival of roof gardens.

Figure 2.7: Photos of existing conditions at the often-flooded mouth of the Don River in Toronto, ON, and a rendering of a design to better accommodate floodwaters while improving amenities. Source: Waterfront Toronto, 2020.

2.3.3 Urban biodiversity

The protection of urban biodiversity (i.e., the variety of life in the urban context) is a priority for many Canadian cities. Tools exist to support cities and towns in urban biodiversity planning (e.g., ICLEI Canada, 2014) and in creating urban biodiversity strategies (e.g., City of Vancouver, 2016); these tools can help address issues such as the arrival of invasive species, which is increasingly likely to occur in a changing climate (Smith et al., 2012). Efforts to preserve green space and biodiversity outside of a city can complement initiatives occurring within municipal boundaries (e.g., Parks Canada, 2014). However, coordinating transboundary and trans-sectoral planning for ecosystem connectivity is becoming increasingly urgent in the face of habitat loss and climate change. Some degree of connectivity is important for the health and survival of almost all species, and local and regional approaches to green infrastructure are likely to provide larger-scale benefits for flood and heat reduction (Satzewich and Straker, 2019).

2.3.4 Urban forests

Urban forests are useful in retaining stormwater, improving air quality, and reducing urban heat (*see* Figure 2.8). To maintain these benefits, it is essential that municipalities manage urban forests in ways that ensure their adaptability to climate change (Diamond Head Consulting Inc., 2017b; Brandt et al., 2017; McDonald et al., 2016). For example, the City of Kitchener is preparing its urban forest for more winter ice storms (City of Kitchener, 2019). For many cities, increasing heat and drought mean that cities need to actively plan to introduce tree species that will not only reduce various climate risks, but will also be resilient themselves to changing climate conditions (Brandt et al., 2016). Cities and towns across Canada are acknowledging this dimension of climate risk, and are developing a deeper understanding of the climate vulnerability of trees (e.g., City of Montréal, 2017). Cities and towns are also prioritizing the health of their urban forests. For example, the urban forest in Kingston, Ontario, provides $1.87 million in environmental benefits annually, and is being actively managed via the city's Urban Forest Management Plan and Drought Protection Strategy (Guilbault et al., 2016). In some neighbourhoods—particularly in dense cities like Montréal and Toronto—the cost of tree planting for particulate matter (PM) reduction is as low as US$840/ton, and rivals commonly used strategies to reduce PM (e.g., point source control) (McDonald et al., 2016). Similarly, the shade provided by trees reduces temperature in the area, with associated reductions in cooling costs (McDonald et al., 2016).

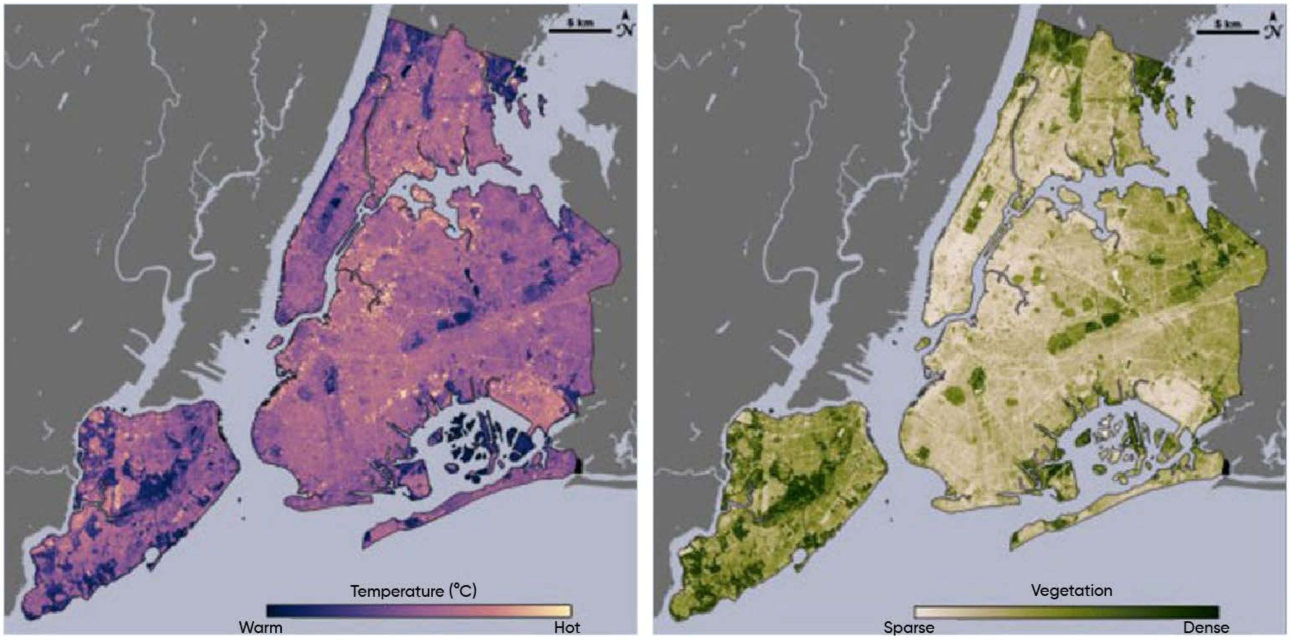


Figure 2.8: A graphical representation of the correlation between urban trees and temperature. Source: NASA Earth Observatory, 2006.

2.3.5 Water supply

Water is an essential resource for cities and towns, and degraded water quality is commonly identified as a potential impact of a changing climate (*see* Water Resources chapter). The provision of clean drinking water is contingent on supply, treatment and delivery, with supply being the primary climate-related challenge. Local governments have always managed variability in supply; however, this occurred within the context of relatively predictable climatic variability (de Loe and Plummer, 2010). The causes of water shortages vary depending on the hydrology within a given region, and vary widely across Canada (de Loe and Plummer, 2010). For example, in rainfall-dominated regions, a water shortage is often caused by decreased summer precipitation, while in snowmelt-dominated regions, earlier or more rapid snowmelt, or a reduced snowpack could be the cause (BC Ministry of Environment and Climate Change Strategy, 2019). Additional factors, such as stormwater management decisions that impact groundwater recharge, also affect municipal drinking water supply and quality (Amec Foster Wheeler and Credit Valley Conservation, 2017).

There have been some assessments of the resilience of water supply treatment and distribution infrastructure. For example, an assessment of Calgary's water supply system found that the system was generally resilient due to robust treatment processes, two raw water sources, and redundancy within the distribution system (Associated Engineering, 2011). Tools also exist to guide the planning process. These often point to the importance of collaborative governance when managing watersheds (e.g., POLIS Project on

Ecological Governance and Centre for Indigneous Environmental Resources, 2019), including the inclusion of Indigenous Knowledge Systems (Porten et al., 2016). An example of this type of governance can be seen in the Cowichan Valley Regional District (CVRD) water use planning process that involved the CVRD, Cowichan Tribes, the Cowichan Watershed Board and Catalyst Paper (Cowichan Valley Regional District, 2018). This process was created in response to significant pressure being placed on the drinking water supply system by factors relating to water demand, land use and a shifting hydrological cycle from climate change (Compass Resource Management Ltd., 2018).

2.3.6 Multifunctional landscape planning

Multifunctional landscape planning offers an emerging alternative to urban development frameworks that utilize built infrastructure, such as buildings, streets or districts, as the central organizing element of the urban fabric (e.g., smart growth and new urbanism). Multifunctional landscapes are explicitly designed to provide synergistic functions (e.g., environmental, social, economic and cultural) that support ecological health and co-benefits at and across the site, neighbourhood, city and regional scales (Kabisch et al., 2017; Sörensen et al., 2016). Ecosystem services are reintroduced or reinforced within the urban fabric by coordinating development around “spatially and functionally integrated systems and networks of protected landscapes” that may be supported with additional complementary built infrastructure (Ahern et al., 2014, p. 255). The approach suggests a greater need for involvement of landscape architects throughout the planning and design process (Canadian Society of Landscape Architects, n.d.; Lovell and Johnston, 2009). Although effective applications of multifunctional landscape approaches are still limited in an urban context (Meerow and Newell, 2017; Lovell and Taylor, 2013), Toronto’s Don Mouth Naturalization and Port Lands Flood Protection project, with its series of proposed terrestrial, wetland and aquatic ecosystems, illustrates a multifunctional space in which ecological function is restored to the benefit of human health, recreation, restoration and built asset protection (*see* Figure 2.7). Since green infrastructure measures often require significant space that developers and others may desire, it is important to take climate change into consideration when contemplating urban growth (Geneletti and Zardo, 2016).

Case Story 2.2: Piloting natural asset valuation in Nanaimo, BC

Cities and towns face the dual challenges of upgrading ageing infrastructure and increasing the resilience of their natural environment. The Municipal Natural Assets Initiative (MNAI) aims to address these challenges by helping municipalities identify, value and account for natural assets in their financial planning and asset management programs (O’Neil and Cairns, 2017), and to consider future climate conditions (Municipal Natural Assets Initiative, 2017). By identifying natural assets—such as wetlands, forests and parks—cities and towns can work to protect them, and can rely on ecosystem services to reduce the load on conventional infrastructure, like underground drainage.

Guided by the MNAI, the City of Nanaimo, BC, sought to assign a financial value to its natural assets, using the Buttertubs Marsh Conservation Area (BMCA) as part of a pilot study. When the opportunity came to participate in the MNAI, the City had just completed a Management Plan update with the Nature Trust of British Columbia and Ducks Unlimited for the BMCA. There was interest in exploring how the City could work more effectively to help implement the conservation plan, while also recognizing its value in mitigating the flows of the Millstone River. The BMCA comprises 55 hectares of reclaimed wetland and floodplain within Nanaimo (*see* Figure 2.9; Molnar et al., 2018). The project found that the BMCA helps moderate the rivers downstream during extreme precipitation events, and therefore reduces flood risk in the floodplain. Building an engineered system that could do what the BMCA does naturally would cost the City between $6.6 and $8.5 million, a figure that would rise with more extreme events. The results of this pilot study will guide the City in identifying other key natural assets to be recognized and integrated into the City's infrastructure (Molnar et al., 2018). Water levels throughout the BMCA have been tracked for the last two years in an ongoing effort to monitor and evaluate the project.

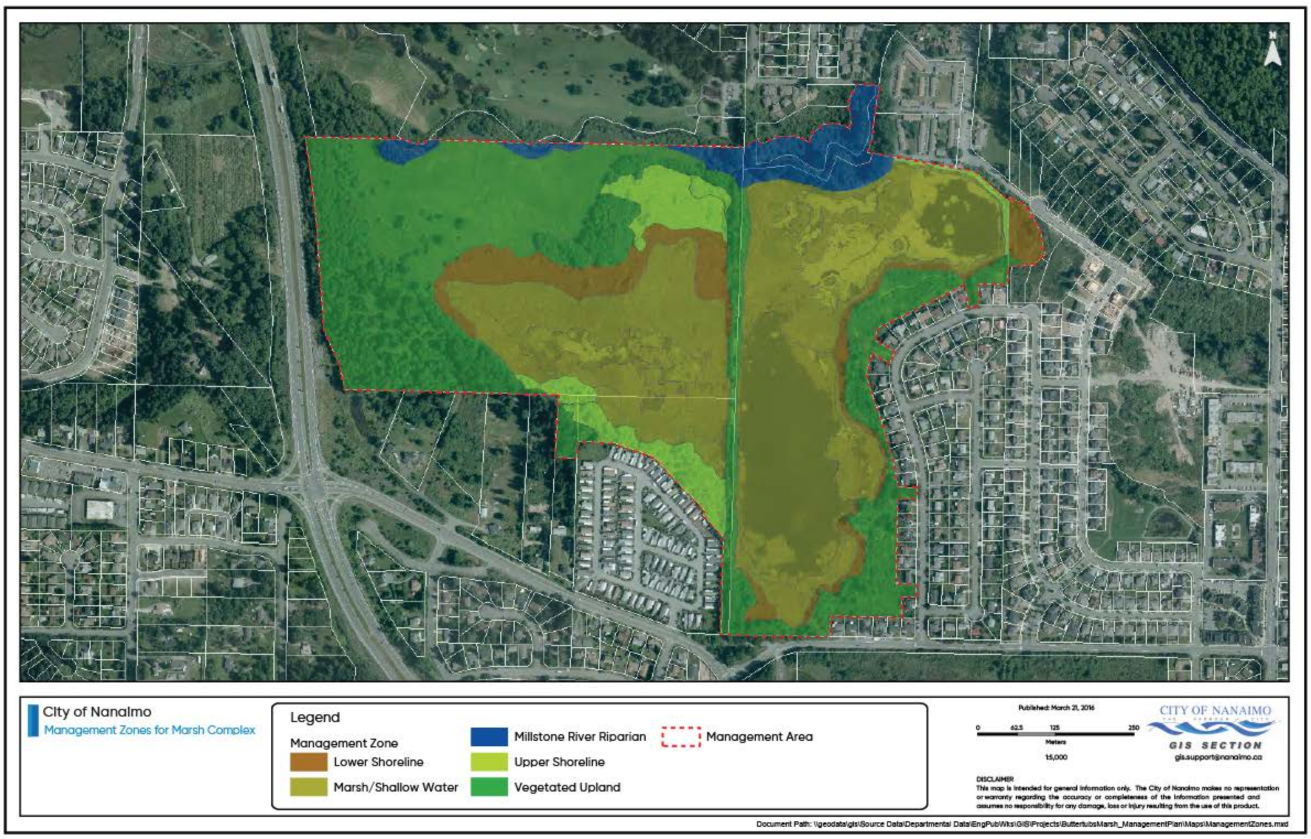


Figure 2.9: The Buttertubs Marsh Conservation Area, which comprises 55 hectares of reclaimed wetland and floodplain, appears in the center (the "management area") of this aerial photo of Nanaimo, BC. Source: City of Nanaimo.

2.4 Climate change will hit those already struggling in cities and towns the hardest

Climate change will impact individual and community health and well-being in cities and towns. However, the negative impacts from climate change will not affect all members of society equally. Considering social equity in adaptation decisions will help reduce the vulnerability of those at highest risk and will ensure that benefits are distributed fairly.

Many of the impacts of climate change on health and well-being—especially those relating to individual physical health—are increasingly well understood (see Health of Canadians in a Changing Climate Report). Adapting to these impacts requires continued collaborations across sectors and consideration of the many non-climate factors that influence health. Understanding and addressing the vulnerability of various urban populations to climate change is essential for increasing both individual adaptive capacity and the overall resilience of urban communities. It continues to be an important area of practice to establish practical linkages between community development, social resilience interventions, initiatives that increase equity, reconciliation and climate change adaptation.

2.4.1 Impacts on individuals and communities

There is strong understanding of the impacts that climate change has on the physical health of individuals (*see* Table 2.2; EPCCARR, 2018; Berry et al., 2014). This understanding is becoming more nuanced and is beginning to include mental health impacts, such as despair and anxiety, as well as post-traumatic stress disorders for those affected by, and responding to, extreme events (Decent and Feltmate, 2018; Gifford and Gifford, 2016). Negative impacts can also result from individuals and communities experiencing grief or loss regarding some aspect of their surroundings that has been altered by climate change (e.g., the loss of cedar trees on Vancouver Island) (Cunsolo and Ellis, 2018). Framing climate adaptation as a public health issue is likely to garner public support for adaptation (Araos et al., 2017; Cheng and Berry, 2013) and is increasingly commonplace in adaptation practice in Canada's cities and towns. Climate change is also affecting the delivery of services by health agencies across Canada (e.g., disease surveillance, air quality monitoring and emergency preparedness) (Buse, 2018).

Negative impacts of extreme weather events and climate change on cultural practices include the loss of landmarks and a reduced ability to engage in recreational and cultural activities, such as bird watching, using public playgrounds and harvesting traditional foods (*see* Figure 2.10; Government of Canada, 2016; Ford, 2012). In Ottawa, for example, Canada Day festivities have been reduced due to extreme heat (Dunham, 2018), and it is likely that skating on the Rideau Canal will decrease in the future (Spears, 2017).

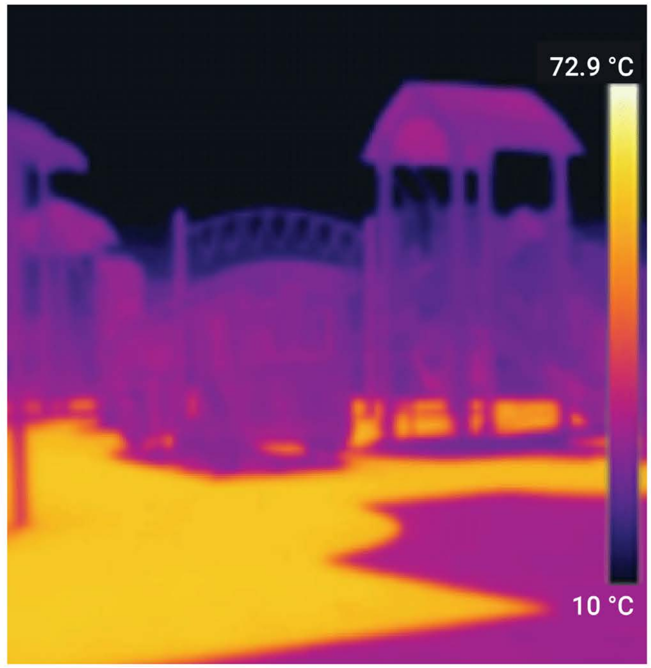


Figure 2.10: Thermal imaging of Windsor's Captain John Wilson park shows that the temperature of the dark rubber mat under the play structure (yellow area) is 69.0°C. Photos courtesy of the City of Windsor.

2.4.2 Social determinants

Climate change can exacerbate existing socioeconomic vulnerabilities (EPCCARR, 2018). Social vulnerability refers to a set of social characteristics (e.g., socioeconomic status, age, ethnicity, housing status) that affect adaptive capacity and that increase the sensitivity of certain populations to climate impacts (EPCCARR, 2018; Cutter et al., 2010). Considering socioeconomic vulnerabilities, including their history and dynamics, helps to ensure that adaptation initiatives do not exacerbate existing inequities and that they are better positioned to maximize benefits for marginalized groups (Shi et al., 2016). The relationship between social vulnerability and climate change is often evident during extreme weather events. For example, Superstorm Sandy "exposed the role that chronic societal stressors—such as poverty, lack of mobility and lack of social cohesion—can play in both increasing community vulnerability and hindering a region's ability to recover from a disaster" (Grannis, 2016, p. 1). Some adaptation plans acknowledge the effects that climate-sensitive hazards can have on homeless populations (e.g., City of Toronto, 2019), and climate change is increasingly being viewed as a risk multiplier for the affordable housing crisis many cities are facing (Ortiz et al., 2019).

Adaptation planning across Canada often takes into consideration those who are vulnerable, including low-income and equity-seeking groups (i.e., groups facing an unequal distribution of opportunities and resources)

(City of Toronto, 2019). For example, the City of Montréal considered social susceptibility by assessing the vulnerability of the following groups to different climate hazards: children aged 0 to 15, seniors aged 65 and up, people living alone, underprivileged people, recent immigrants and people who speak neither French nor English (City of Montréal, 2017). Indeed, the majority of the 53 heat-related deaths in Montréal's 2018 heat wave were men older than 50 years of age who lived alone (Santé Montréal, 2018). Box 2.4 describes impacts and adaptation relating to extreme heat events in cities and towns in more detail. Ideally, climate adaptation and resilience efforts would complement existing social vulnerability reduction efforts, including by mainstreaming.

Wildland-urban interface fires are projected to increase in frequency and will continue to cost more than fires that threaten only forest resources (Mahmoud and Chulahwat, 2018; Canadian Council of Forest Ministers, 2013). The impacts of these fires include mortality, negative mental health effects (e.g., generalized anxiety disorder), displacement and respiratory illness. Particulates from wildfire smoke can affect air quality and health across great distances. These impacts are often most pronounced for vulnerable populations, including children, the elderly, pregnant women, people of low socioeconomic status, as well as first responders (National Collaborating Centre for Environmental Health, 2019b; Abbott and Chapman, 2018; Agyapong et al., 2018; Ford, 2012).

Box 2.4: Extreme heat

The urban heat island effect results from the prevalence of hard surfaces in cities that store heat, often leading to higher daytime and nighttime temperatures (McDonald et al., 2016). This rise in temperature amplifies the risks that cities face during extreme heat events, which are expected to increase in frequency and intensity as the climate changes (*see* Figure 2.11; Zhang et al., 2019), along with the number of heat-related mortalities (Guo et al., 2018). The negative health impacts associated with extreme heat events are well understood (*see* Video 2.1; National Collaborating Centre for Environmental Health, 2019a; Lebel et al., 2017). Multiple organizations, including local and provincial governments, health authorities and the federal government, often lead heat response efforts in Canada. Montréal's heatwave plan involves "monitoring signs of heat-related illness, frequent visits to home-care patients, opening air-conditioned shelters, extending pool hours and mass media communication campaigns" (Araos et al., 2017, para 9). These efforts are estimated to have reduced heat wave-related mortalities by 1.52 deaths per day during heat events in Montréal (Benmarhnia et al., 2016).

In Toronto, only 128 of the 583 schools in the Toronto District School Board have air conditioning, which exposes students and workers to significant heat stress, and can prompt parents to keep children home from school (Flanagan, 2018). Retrofitting the schools with air conditioners would cost roughly $750 million, and so temporary cooling centres are set up in libraries and gyms (Flanagan, 2018). Many high-rise residential buildings also lack air conditioning, and some local governments have implemented adaptation initiatives to address this problem. For example, the City of Hamilton trained landlords to deal with extreme heat by providing common rooms with air conditioning, and having superintendents identify heat-related health symptoms, and check in on vulnerable residents (Guilbault et al., 2016). Health authorities in British Columbia are exploring the role that passive cooling strategies can play in maintaining safe operating conditions in buildings, in order to avoid increasing greenhouse gas emissions through mechanical cooling (Lower Mainland Facilities Management, 2018).

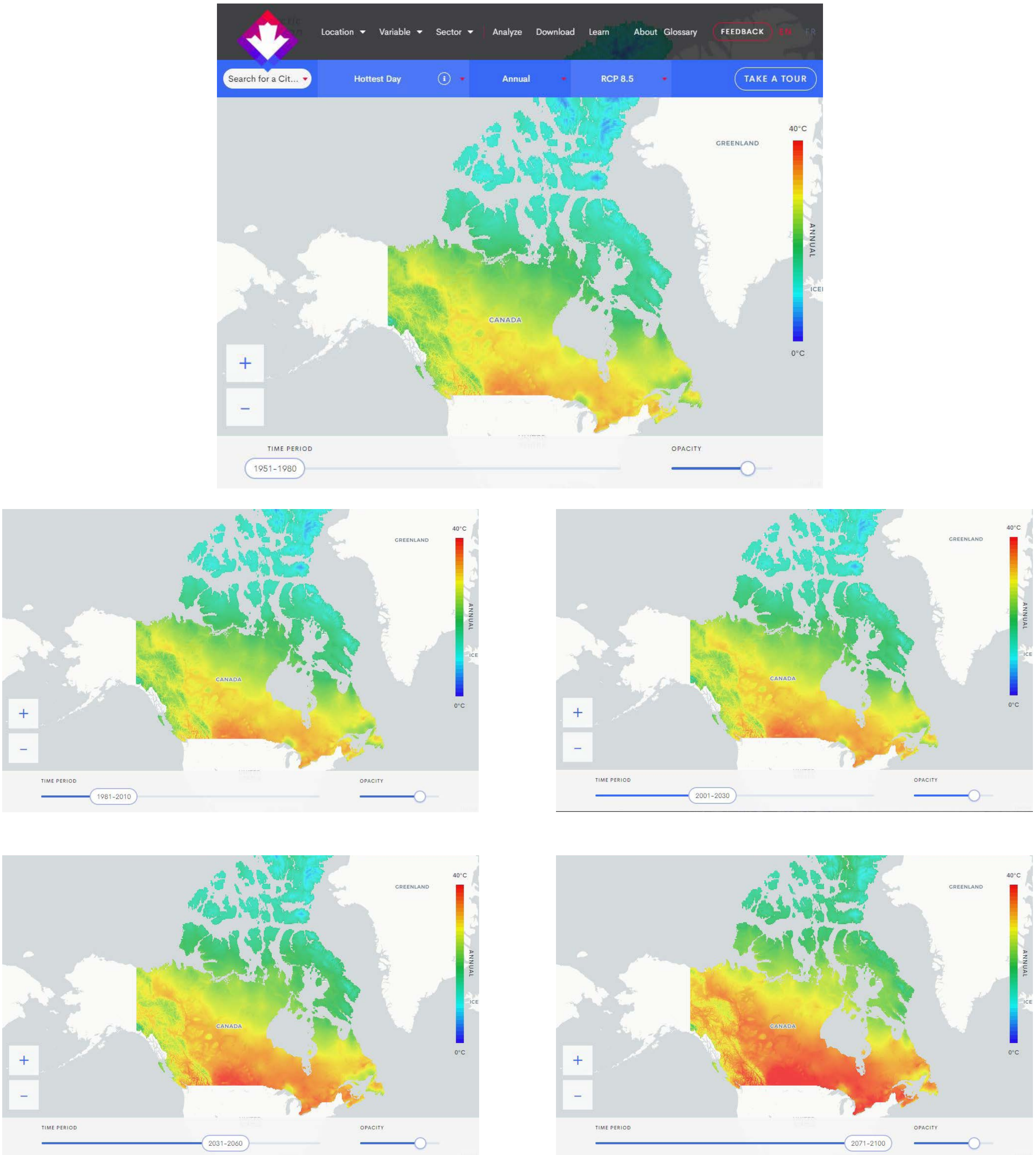
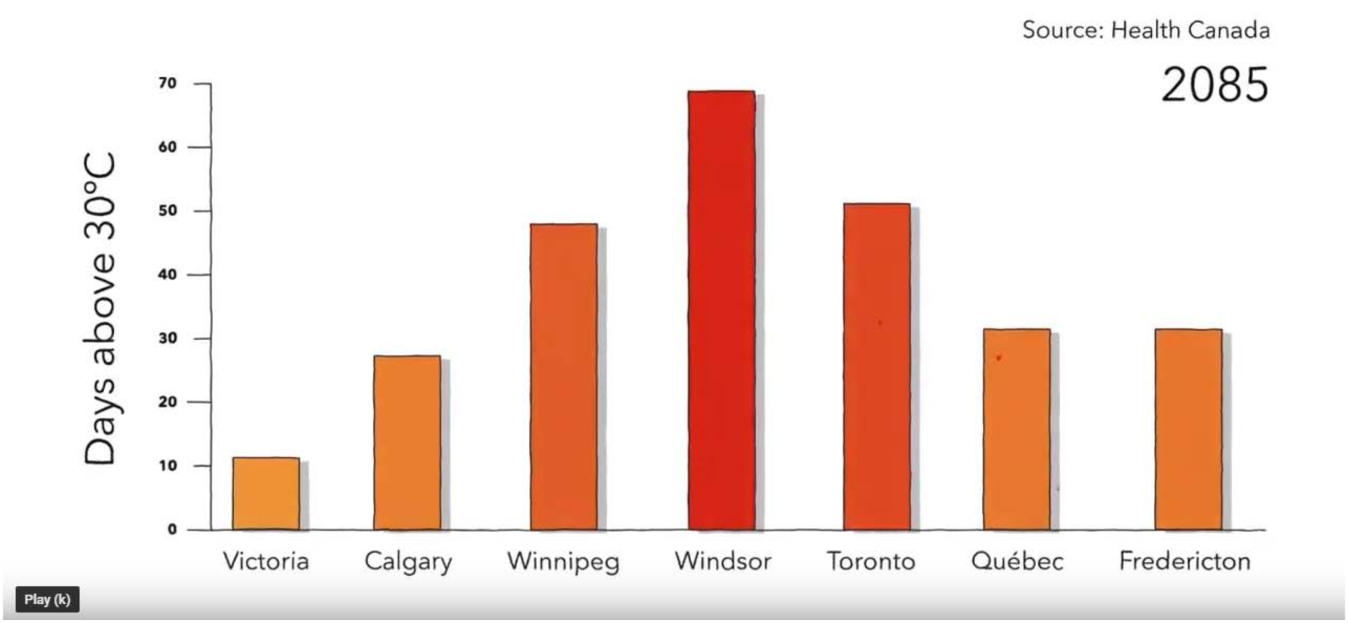


Figure 2.11: This map is from climatedata.ca and displays the “hottest day” variable across multiple timescales.



Video 2.1: The National Collaborating Centre for Environmental Health has produced a video about the impacts of and adaptations to urban heat. Source: National Collaborating Centre for Environmental Health, 2018. <https://youtu.be/RBwgS_1D5FM>

2.4.3 Strong social systems

In addition to built infrastructure, cities and towns also have social infrastructure, complete with assets that include community centres, trust and social cohesion (Carter et al., 2015; Kenton, 2014). Social resilience is a necessary, but insufficient condition of climate resilience (Kwok et al., 2016). It encompasses a number of factors, including social capital, innovation, a strong economy and inclusivity (Gibberd, 2015). For example, social capital—which is a measure of social cohesion, agency, trust and social learning (Walker et al., 2014)—helped reduce the number of injuries and fatalities in the 2013 floods in Calgary (Haney, 2018). Similarly, during the agenda-setting workshop for Calgary's 100 Resilient Cities initiative, "participants noted that successful responses to shocks are frequently driven by grassroots efforts and rely on cohesive and connected communities that can assemble quickly" (City of Calgary, 2017, p. 10). Interestingly, participants also pointed out that social media—primarily Twitter—enabled rapid community mobilization.

There are many examples of social resilience building exercises in Canada, several of which are motivated by an emergency management imperative, or by health and well-being agendas. For example, the City of Vancouver's Healthy City Strategy sets the following target: "all Vancouverites report that they have at least 4 people in their network they can rely on for support in times of need" (City of Vancouver, 2015, p. 26). Vancouver's "Hey Neighbour!" program is a resident-led initiative aimed at increasing social connectedness, neighbourliness and resilience in multi-unit buildings (City of Vancouver, 2019a).

2.4.4 Increasing equity

Equitable climate change adaptation involves understanding the inequitable nature of climate impacts, and ensuring broad representation in the planning, implementation and delivery of adaptation initiatives. Creating equity is understood to increase adaptive capacity and well-being in cities (Rosenzweig and Solecki, 2018), and can also increase the likelihood of climate resilience measures being implemented (Gonzalez et al., 2017), though this has not been explored empirically in Canada. In order to achieve this, equity must be present in both the processes and outcomes of climate adaptation activities (Doorn, 2017). This issue is sometimes characterized as the "resilience for whom" question (Meerow et al., 2016). For example, Video 2.2 demonstrates the importance of involving youth in climate action.

Equitable climate adaptation is an emerging trend in Canada, and an increasing body of international best practices inspire and direct action here in Canada. For example, infrastructure designers in the United States are being urged to consider the extent to which their designs prioritize equity and inclusion (Climate-Safe Infrastructure Working Group, 2018, p. xi). Similarly, the City of Portland, Oregon has incorporated equity into its climate preparedness plan (City of Portland, 2014). These sentiments were echoed in the October 2019 Victoria Call to Action (*see* Case Story 2.3).

Video 2.2: This video describes the importance of youth perspectives. Source: ResiliencebyDesign Research Innovation Lab, 2017. <https://youtu.be/bQg42VCZegk

2.4.5 Place-based adaptation

Place-based approaches to adaptation recognize the importance of social resilience by organizing adaptation efforts around community spaces that support social bonding and elicit a strong sense of place attachment (Adger et al., 2011). For example, the City of Toronto created ten resilience hubs across the city that engaged diverse local residents to design resilience projects in their communities (City of Toronto, 2019). When knowledge pertaining to community spaces and their value to communities is overlaid with scientific knowledge about impacts, new opportunities for participatory dialogue between stakeholders and local citizens can emerge (Amundsen, 2015). The spatial structure of place attachments can be examined through engagement techniques like participatory GIS mapping (Brown and Raymond, 2014), while more experiential approaches like collaborative citizen science projects can foster scientific learning about climate change while simultaneously enabling a deeper sense of place (Groulx et al., 2017; Newman et al., 2016). When adaptation planning focuses on the place-based values that are unique to different communities, citizens gain greater access to, and influence over, defining what is important to protect through adaptation (Amundsen, 2015). At the same time, technical experts gain a local framework for discussing climate change that may reveal potentially overlooked impacts and sources of vulnerability (De Dominicis et al., 2015; Marshall et al., 2012). Orienting resilience-building towards places that foster our traditions and livelihoods, house individual and shared histories, and impart a sense of our identity can also support implementation by garnering public support to protect places from climate-driven environmental change (Nicolosi and Corbett, 2018; Masterson et al., 2017; Adger et al., 2013; Devine-Wright, 2013).

Case Story 2.3: Victoria Call to Action: Building resilience through thriving and inclusive communities

In October 2019, more than 50 mayors and councillors from across Canada gathered in Victoria, BC as part of the Livable Cities Forum to discuss and share ideas on building social resilience, community belonging and inclusion as a key resilience strategy (ICLEI Canada, 2018b). The session culminated with elected officials finalizing a collective Call to Action for local leaders to advance work on the health, well-being and social cohesion aspects of resilience. The Victoria Call to Action was endorsed by those locally elected officials present as a call to themselves and other locally elected officials to take action and commit to the following six points of action:

1. Ensure that all actions we take are done through a lens of decolonization, health and well-being, equity and inclusion, racial and social justice, and ecological integrity.
2. Empower and resource our communities and use our role as leaders to create opportunities for education, connection, belonging and community building.
3. Enrich the fabric of our communities by building towns and cities that create a sense of place and

a strong connection to neighbourhoods.

4. Leverage the interconnection of issues and look for opportunities to solve complex challenges that generate multiple benefits and solutions.
5. Seize the pockets of brilliance in our communities coming from youth and residents as bottom-up solutions to our collective challenges.
6. Invest our collective resources to deliver short- and long-term solutions that will have the greatest impact and help us go further, faster together.

2.5 Working together yields the most successful outcomes

Effective adaptation approaches to climate change consider diverse perspectives and priorities. Local governments are increasingly playing a strong role in driving meaningful collaboration with different groups when it comes to designing, planning and implementing adaptation in their communities.

Initiatives that help make Canada's cities and towns more resilient to a changing climate are more effective when they are collaborative. Collaboration that is inclusive, transparent, and incorporates diverse perspectives, from the initial planning phases right through to adaptation implementation, enhances outcomes for all. Local governments are well-placed to bring groups together to share their unique perspectives and priorities, create solutions, and implement action. As such, strengthening local government capacity to plan and implement adaptation would help build adaptation momentum in cities and towns.

2.5.1 Introduction

Climate change adaptation in Canada's cities and towns is motivated by local governments' need to ensure levels of service for their communities, as well as by policies and resources at the federal (Henstra, 2017) and the provincial levels. For example, Nova Scotia required its municipalities to create climate action plans (Climate Change Nova Scotia, 2014), and other provinces have developed planning tools and resources to help cities incorporate adaptation into land-use planning (Government of Ontario, 2017; Legislative Assembly of Ontario, 2017).

Cities and towns operate within a governance context that includes provincial and federal entities, alongside their own staff, councils, residents and businesses (*see* Box 2.5 and Case Story 2.4). Although complex, this context presents an opportunity for effective action on adaptation (Paterson et al., 2017; Graham and

Mitchell, 2016; Revi et al., 2014).

2.5.2 Co-production

Participatory, collaborative planning approaches embracing and leveraging the viewpoints of multiple actors are viewed as essential for successful adaptation in cities (Archer et al., 2014; e.g., Auditor General of Canada, 2018; Wamsler, 2017; Revi et al., 2014; Burch et al., 2010). Such approaches are usually described as "inclusive, transparent, participatory, multi-sectoral, multi-jurisdictional and interdisciplinary" (Rosenzweig and Solecki, 2018, p. 757). Co-production allows multiple parties to find ways to combine their efforts and capacities towards achievement of a common goal (Wamsler, 2017). Co-production can occur at all points in the adaptation process, including risk assessment, setting objectives, implementation activities, and monitoring and evaluation. This is an equitable approach that also increases the likelihood of implementation, which is partially contingent on those impacted by a changing climate being aware, empowered to act and capable of creating change (Birkholz et al., 2014).

2.5.3 Municipal governments

Municipal governments help drive climate adaptation in Canada, as they are motivated by impacts in their jurisdictions affecting levels of service and budgets (Dale et al., 2013). While Video 2.3 demonstrates the important role that municipal planners play in climate change adaptation, adaptation also includes staff from across municipal departments (e.g., parks, engineering). Municipal governments can use numerous regulatory tools to drive land-use planning decisions that consider climate change impacts. For example, development limitations can increase the resilience of natural systems (Terton, 2017) and help cities to mitigate risks relating to wildland-urban interface fires (Kovacs, 2018).

Local governments are increasingly encouraged—in the literature and through policies—to create more meaningful engagement with multiple actors (Canadian Institute of Planners, 2018; Mees, 2017). For example, in the collaborative work in the Bras d'Or watershed on Cape Breton Island, municipalities are working with First Nations, provincial governments, federal agencies and citizens to ensure the health of the watershed into the future (Bras d'Or Lakes Collaborative Environmental Planning Initiative, 2018). Similarly, the Fraser Basin Council Lower Mainland Flood Management Strategy is a collective approach to coastal and river flooding resilience that involves 23 municipalities and numerous community organizations (Fraser Basin Council, 2018).

Video 2.3: This video highlights the role of planners in the adaptation process. Source: Climate Atlas of Canada, 2018. <https://climateatlas.ca/video/planning-climate-resilience

2.5.4 Private and public sectors

Cities and towns are sites of concentrated economic activity. Climate change can undermine community resilience by affecting physical assets, disrupting supply chains and business networks, and affecting workers (Decent and Feltmate, 2018; Hunt and Watkiss, 2011). The connection between economic resilience and climate resilience is increasingly being recognized. For example, as part of its involvement in the "100 Resilient Cities" international network, the City of Calgary (along with Toronto, Montréal and Vancouver) connects the health of its economy to its ability to remain resilient in the face of extreme weather events (Nenshi, 2018). Effective adaptation enables cities and towns to maintain favourable credit ratings and property values in the face of a changing climate, thus positioning cities as favourable sites for investment and in-migration (McCullough, 2018). This has led to cities like Toronto and Vancouver participating in the Task Force for Climate-related Financial Disclosure (*see* Climate Disclosure, Litigation and Finance chapter). Similarly, ensuring business continuity is essential to a city's ability to function during and after an extreme event.

Private sector businesses, and public sector organizations like universities, health authorities/organizations, and provincial/federal governments, are also important partners for municipal governments. These actors often own significant assets in cities and towns, and provide essential services. Health authorities and municipal governments, for example, are interdependent in that health authorities depend on municipal infrastructure to deliver health services that are essential to cities and towns. Creating meaningful partnerships early in the adaptation planning process will help create the relationships that are essential in the implementation phase, where multiple actors are responsible for implementation actions within their mandate (*see* ICLEI Canada, 2020 for examples of this approach).

2.5.5 Citizens

Citizens are central to co-production of adaptation approaches in cities and towns (Cloutier et al., 2018; Wamsler, 2016). Individuals drive political will, participate in citizen-science monitoring programs (e.g., City of Vancouver, 2019b), and create and implement adaptation initiatives. For example, homeowners are increasingly responsible for protecting themselves from flooding and other extreme weather, and for financing their own recovery through private insurance (Henstra et al., 2018; Kovacs et al., 2018). Local governments can encourage residents to take property-level actions by offering direct incentives for the purchase, installation, or construction of certain adaptive measures. Incentives and rebates can be coupled with policy initiatives to encourage property owners to take adaptive measures beyond those mandated by a local bylaw or regulation (Zerbe, 2019). There are also a number of programs that target building owners (e.g., Victoria's Stormwater Utility), encouraging them to effectively manage stormwater, but uptake has been sporadic (Canadian Standards Association, 2018; Thistlethwaite et al., 2018; Kovacs et al., 2014; Chambers, 2013; Sandink, 2013b).

Effectively encouraging individuals to take action on climate adaptation involves engagement in co-production of risk perception, action planning, and implementation. This involvement can be achieved through community-based organizations (Gonzalez et al., 2017). For example:

- West Vancouver's urban shoreline rehabilitation was spurred by the West Vancouver Shoreline Preservation Society (Centre for Civic Governance, 2018);
- The use of sand dunes in Hamilton involved experiential learning for students that was spurred by Environment Hamilton and the Hamilton Naturalists' Club, with the help of the City of Hamilton; and
- Green Communities Canada's RAIN Community Solutions program works with homeowners to implement low impact development initiatives (RAIN Community Solutions, 2020).

2.5.6 Boundary organizations

Boundary organizations help to translate science and Indigenous Knowledge Systems into practice, build capacity, contribute analysis, and convene co-production processes (Bauer and Steurer, 2014). Boundary organizations can include not-for-profit organizations, private consultants, researchers or even government agencies (Graham and Mitchell, 2016). Effective boundary organizations provide credible, legitimate and salient information and action to cities, and help with implementation (Graham and Mitchell, 2016). As described in Section 2.4, health organizations are increasingly developing programming that explicitly builds adaptive capacity.

Box 2.5: Urban flooding

Urban flooding associated with impervious surfaces, inadequate drainage infrastructure, and short-duration, high-intensity rainfall events is one of the most significant drivers of disaster loss in Canada (Insurance Bureau of Canada, 2018; Friedland et al., 2014) and is expected to become more common in a changing climate (Gaur et al., 2019; Canadian Standards Association, 2018; Amec Foster Wheeler and Credit Valley Conservation, 2017). During these events, local governments face decreased capacity to act, increased operational and repair costs, and can also be exposed to the risk of legal liability (Zizzo et al., 2014; City of Stratford, 2010; Campbell et al., 2007). Additionally, the flooded basements that are a hallmark of these events cause property damage, displacement, loss of irreplaceable and sentimental items, and negative physical and mental health impacts (Decent and Feltmate, 2018; Feltmate et al., 2017), as well as reduced insurance coverage for future events (Sandink, 2016).

Managing these risks requires structural and non-structural responses (e.g., improved land-use planning). An important non-structural approach is insurance coverage for overland flooding. This type of coverage is improving in Canada (Meckbach, 2018), but its success requires a high degree of capacity to act on the part of homeowners, insurers and all levels of government (Henstra et al., 2018). Cities and towns, for example, need to improve risk planning and mitigation in order to increase the commercial viability of residential flood insurance (Insurance Bureau of Canada, 2015). Additional barriers include lack of flood hazard awareness (Thistlethwaite, et al., 2018; Sandink, 2016), limited understanding of the specifics of home insurance coverage (Oulahen, 2015; Sandink et al., 2010), an inaccurate understanding of the level of post-disaster assistance available from provincial and federal governments (Henstra et al., 2018), and a host of socio-psychological factors (McDonald et al., 2015; van der Linden et al., 2015).

Awareness of flood hazards through updated flood mapping (*see* Figure 2.12 as an example) has been associated with increased uptake of voluntary insurance coverage for floods (Shao et al., 2017), and also as important enabling evidence for the development of flood control bylaws (e.g., Prince George's floodplain bylaw). The need for such mapping is increasingly being met by a variety of government programs (e.g., Public Safety Canada's National Disaster Mitigation Program) as well as by academics (Thistlethwaite et al., 2018). In 2018, Natural Resources Canada released additional guidance on floodplain mapping, as well as a series of case studies (Natural Resources Canada, 2018). However, flood mapping is most effective if it makes its way into regulation. The town of Paradise, Newfoundland, for example, has plans to update its bylaws to reflect the flood risk mapping shown in Figure 2.12 (Town of Paradise, 2016).

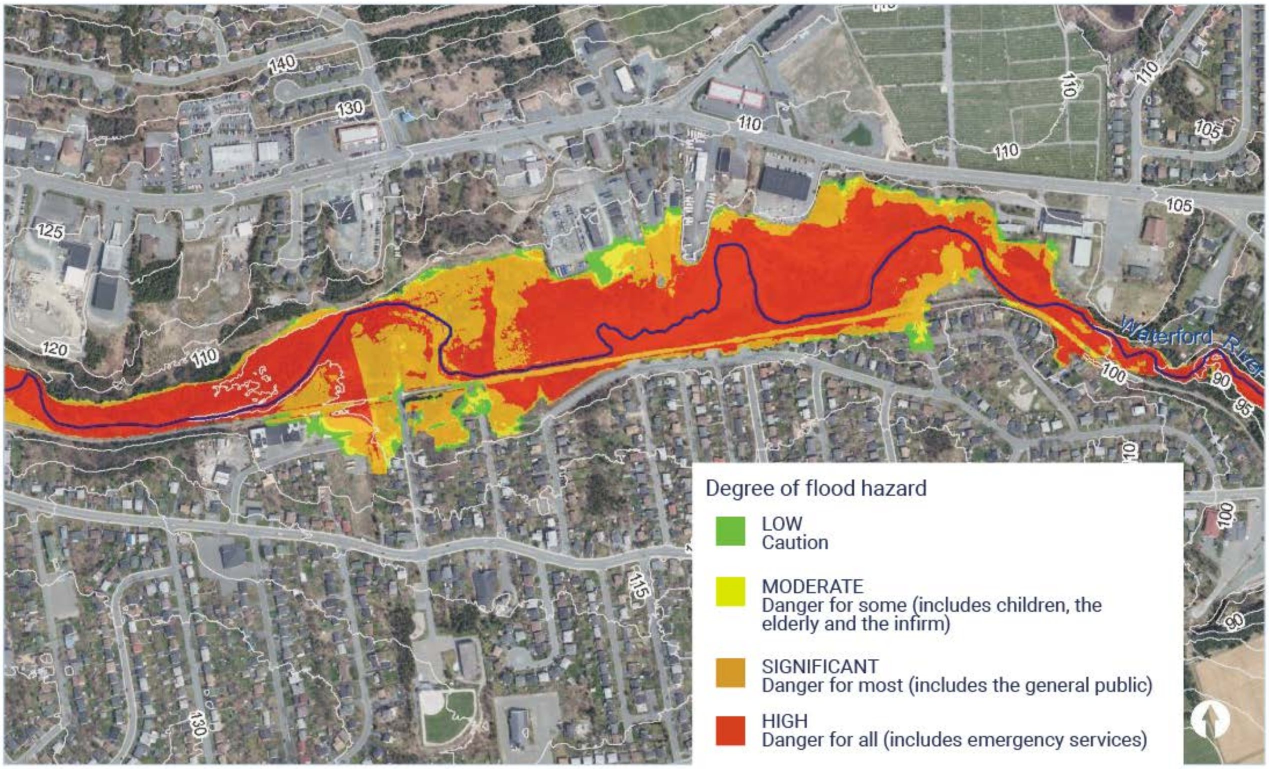


Figure 2.12: An example of a flood hazard map for the municipalities of St. John's Mount Pearl and Paradise in Newfoundland and Labrador. Source: Natural Resources Canada, 2018.

Case Story 2.4: Brampton Lighthouse Project: Supporting vulnerable populations during extreme weather events

The City of Brampton's Lighthouse Project is a collaboration between the City and 20 of its faith-based organizations (FBOs) (Keam and Murray, 2018). This collaboration allows FBOs to provide support to vulnerable populations during extreme weather events and non-climate-related emergencies. FBOs provide pre-screened volunteers, places of refuge, wellness checks on members, emotional counselling and donation management (Cummings, 2017). The City provides resources, including training, identification cards and signage, promotional material, some equipment, support for community grants, and liability and Workplace Safety and Insurance Board insurance coverage during emergencies (Cummings, 2017). Extensive work was required to structure these partnerships.

Faith and the Common Good, a national, non-sectarian charitable network, provided evidence in support of this concept with a preliminary study that explored how FBOs could be better utilized to provide local service centres during extreme weather emergencies (Cummings, 2016). The study found that, in addition to owning a large number of physical assets (e.g., buildings, parking lots), FBOs also have a history of serving vulnerable populations. A mapping exercise identified the locations of FBOs in relation to known vulnerable populations (*see* Figure 2.13). This mapping revealed favourable conditions in Brampton, and thus the project was pursued. A crucial element of the project was the inclusion of Brampton's legal and risk division, which was able to create a capacity-building agreement that enabled and formalized the partnership. A "Champions Kit" was also produced to encourage new FBOs to join the program. Numerous metrics are used to gauge the effectiveness of the program, including the level of participation in FBO training workshops, follow-up interviews with FBOs after the workshops, and expressions of interest from other community groups and municipalities to participate (ICLEI Canada, 2018a).

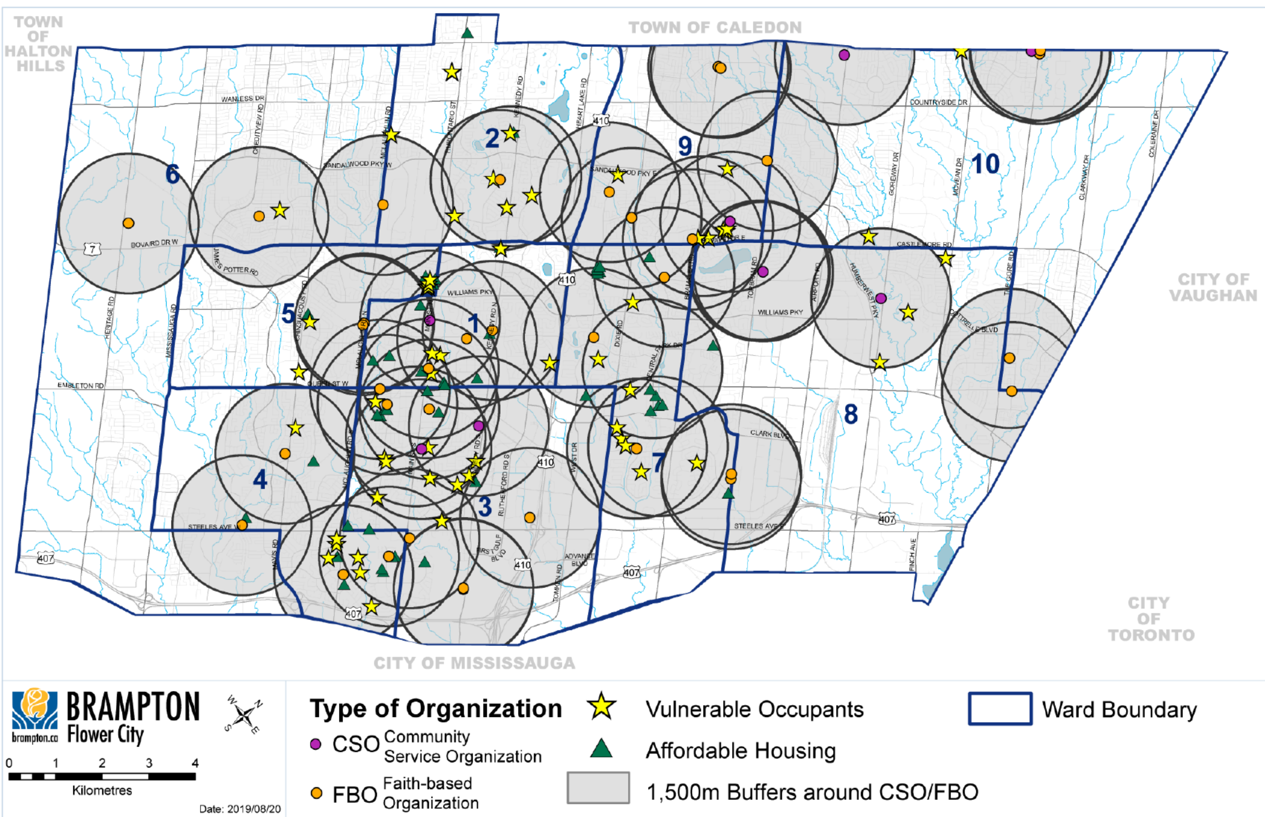


Figure 2.13: A map showing the location of Faith-Based Organizations, affordable housing and vulnerable occupants. Source: Courtesy of the City of Brampton, 2019.

2.6 Indigenous peoples in cities and towns are often affected in unique ways by climate change

Canada's cities and towns are home to large populations of Indigenous peoples, who are often affected in unique ways by a changing climate. Attention is being given to Indigenous issues, and the inclusion of Indigenous perspectives and expertise in municipal adaptation planning processes is occurring, but this is not widespread. Strengthening collaboration with Indigenous peoples will require increased capacity and additional research.

Indigenous people living in Canada's cities and towns will face all of the climate change impacts described throughout this chapter, as well as unique impacts that Indigenous communities have long experienced and understood, (Whyte, 2017). These impacts are related to land and territory, community well-being and culture. Efforts to address the impacts of climate change on Indigenous people and communities in cities and towns should be informed by the broader context of colonialization and should involve Indigenous-led organizations. Creating meaningful collaborations with Indigenous organizations will enhance the inclusiveness of adaptation approaches in cities and towns. Best practices are starting to emerge in Canada, although more research and practice are needed.

2.6.1 Introduction

All cities in Canada are built on the traditional territories of First Nations, Métis or Inuit peoples. As Canadian cities were founded and settled, First Nations peoples were often purposefully relocated from cities to reserves (Peters et al., 2018). Nevertheless, Canada's cities and towns are home to large populations of First Nations, Métis and Inuit peoples.

Many First Nations, Métis and Inuit peoples living in urban areas are either living in their traditional territory, or continue to have strong ties to their home territories (Snyder and Wilson, 2012; Peters and Robillard, 2009; Peters, 2004). Thus, while some First Nations, Métis and Inuit people are disconnected from their communities of origin, many continue to be connected and to engage in traditional land-based activities such as hunting and fishing (Wilt, 2016). When considering how climate change affects urban Indigenous peoples and resilience, it is important to think beyond the city limits, and to understand the broader relationships that mediate both climate change impacts and adaptation strategies (*see* Case Story 2.5).

The population of urban First Nations, Métis and Inuit peoples is growing across Canada (Statistics Canada, 2017b). According to the 2016 Census, Winnipeg, Edmonton, Vancouver, Toronto and Calgary are the cities with the largest population of First Nations people, followed by Calgary, Ottawa-Gatineau, Montréal, Saskatoon and Regina (*see* Figure 2.14; Statistics Canada, 2017c). Trends are similar for Métis and Inuit. One quarter of Métis people in Canada live in cities (Statistics Canada, 2018). Although three-quarters of Inuit live in Inuit Nunangat, four out of ten of the Inuit people living elsewhere reside in large cities. Edmonton, Montréal, Ottawa-Gatineau, Yellowknife and St. John's have the largest populations of Inuit (Statistics Canada, 2018). First Nations, Métis and Inuit urban communities are diverse and often made up of people from many different nations. In many cities, First Nations, Métis and Inuit are dispersed throughout the city, and do not live in concentrated neighbourhoods (Howard and Proulx, 2011; Environics Institute, 2010). Cities are important sites of Indigenous governance. Many cities are home to vibrant organizations representing the interests of First Nations, Métis and Inuit. Friendship Centres, social service organizations, such as child and family service agencies or housing co-operatives, as well as health care agencies, are important sites for Indigenous governance in cities (Tomiak 2010; Peters, 2004). These organizations are important interlocutors for municipal governments. At the same time, the creation of urban reserves in some cities and urban expansion into First Nations communities invite collaboration between First Nations and municipal governments. Many Indigenous communities and governments are developing their own climate change strategies of relevance to neighbouring municipalities.

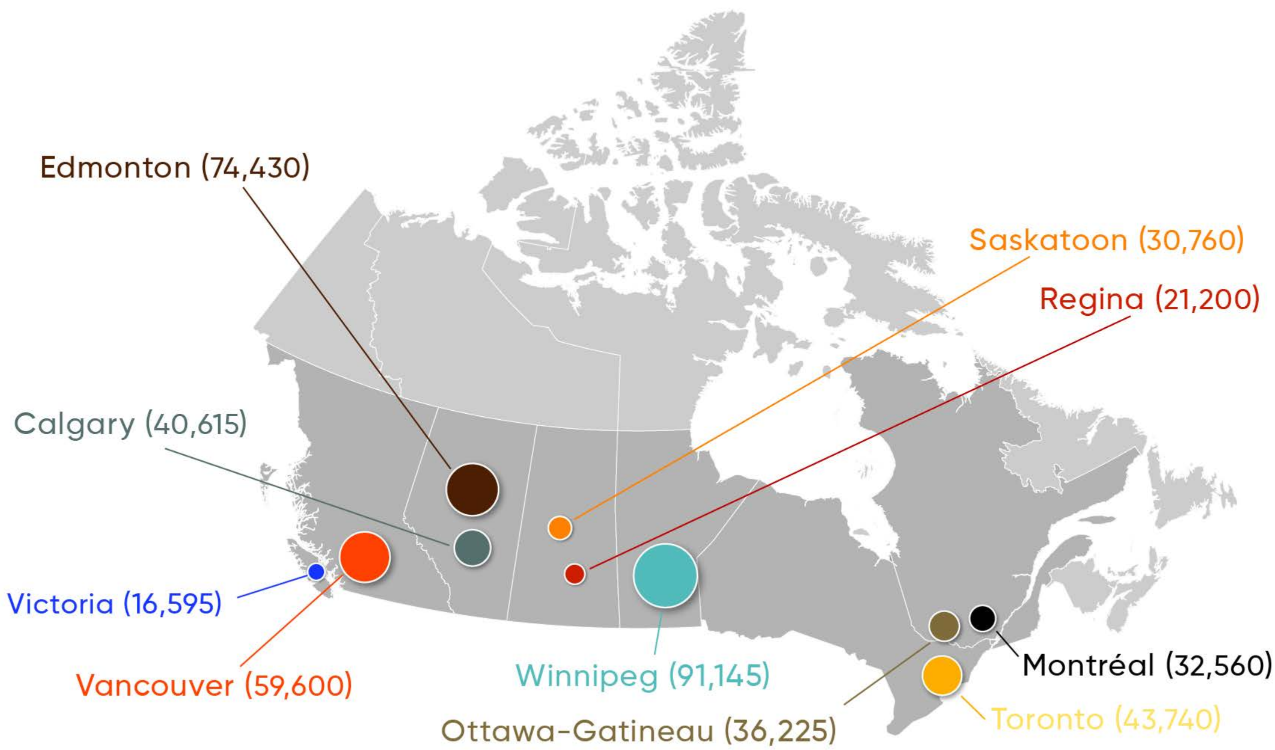


Figure 2.14: Map illustrating the Canadian cities with the largest Indigenous populations. Data source: Indigenous and Northern Affairs Canada, 2016.

2.6.2 Climate change impacts for First Nations, Métis and Inuit peoples

Literature that directly addresses specific impacts of climate change on First Nations Métis and Inuit in cities and towns is relatively scarce. However, there is a large body of literature that examines the effects of climate change on Indigenous peoples in Canada in general, and internationally. This literature demonstrates that, globally, Indigenous peoples have already been significantly affected by climate change, with effects including displacement from traditional territories, and impacts on food security and health, as well as sovereignty and self-government (Whyte, 2016; Ford, 2012, 2009; Turner and Clifton, 2009).

Some climate change adaptation measures can negatively impact Indigenous peoples living within cities, as well as those living a considerable distance away. For example, the operation of aspects of Winnipeg's floodwater infrastructure during the 2011 Manitoba floods caused the flooding of four First Nations communities, resulting in multi-year displacement (Blais et al., 2016) and a class action lawsuit (The Globe and Mail, 2017). The flooding destroyed roads and housing as well as wild rice beds, which are a source of sustenance and economic activity for First Nations. The psycho-social effects of the lengthy displacement were acute (Thompson et al, 2014; Ballard and Thompson, 2013). According to community leadership, at least five of the evacuees died by suicide during the period of extended displacement (CBC News, 2016), reflecting the degree of hardship such displacement causes.

Cities thinking about climate change adaptation must consider how related initiatives could impact Indigenous peoples within and beyond urban boundaries, as well as how Indigenous peoples bring indispensable knowledge, perspectives, and expertise to help identify and develop adaptation solutions. This kind of collaboration requires capacity building on the part of non-Indigenous governments, which must work to understand these important perspectives and to work with Indigenous peoples and governments in order to build upon this knowledge in a respectful and impactful way.

2.6.3 Indigenous Knowledge and climate change

First Nations, Métis and Inuit communities and scholars have stressed the importance of using Indigenous Knowledge Systems in addition to Western science when addressing climate change (EPCCARR, 2018). A growing body of research explores the sources and content of Indigenous Knowledge Systems, as well as the ethical and practical considerations related to the incorporation of Indigenous Knowledge into environmental governance regimes (McGregor, 2014, 2013; Patrick, 2013; Whyte, 2012). Many authors stress that the core of Indigenous environmental knowledge is fundamentally about creating the kinds of relationships that sustain life (Whyte, 2018; Kimmerer, 2011; McGregor, 2005). Thus, rather than taking knowledge about the environment as its object, Indigenous environmental knowledge systems emphasize environmental relations, and the actions that create these relations. As McGregor (2005, p. 104) writes, "It is not just about understanding the relationship with Mother Earth, it is the relationship itself." Many authors have stressed the significance of Indigenous Knowledge Systems for sustaining Indigenous sovereignty (Whyte, 2017). Indigenous Knowledge Systems invite a holistic approach to climate change that addresses not only environmental outcomes, but also political and social factors. For Indigenous peoples, this means that addressing the restoration of Indigenous political and territorial authority and advancing reconciliation are fundamental steps to mitigating and adapting to climate change.

2.6.4 Adaptation and reconciliation

Indigenous environmental knowledge has often been used to inform environmental planning and resource management in rural and remote areas. However, this knowledge has rarely been applied within urban contexts (Porter, 2013). Yet, it is clear that First Nations, Métis and Inuit peoples must be involved in the design and implementation of climate change adaptation initiatives (Government of Canada, 2016). This position is becoming increasingly recognized in Canada. For example, in its policy on climate change planning, the Canadian Institute of Planners (2018, p. 5) supports that "local Indigenous Knowledge and planning traditions are integrated into planning processes, respecting the rights of Indigenous peoples."

Although little research currently exists discussing how this might be accomplished in urban contexts, some Canadian cities are beginning to explore the possibilities, and are engaging Indigenous peoples in the development of climate change resilience strategies. For example, participants in the creation of a resilience strategy for the City of Toronto found that "building bridges between First Nations, Indigenous, Métis and Inuit peoples, and industry and resilience infrastructure projects is a foundational part of the resilience building process" (City of Toronto, 2018). This process was facilitated by the Indigenous Climate Action Network.

Similar initiatives are occurring elsewhere. For example, Calgary's Indigenous relations efforts are viewed as integral to the city's social resilience (City of Calgary, 2017). Similarly, the City of Surrey, British Columbia, is engaging the Semiahmoo First Nation in the development of its Coastal Flood Adaptation Strategy (City of Surrey, 2018).

Case Story 2.5: Community climate change resilience planning in the Tsleil-Waututh Nation

Tsleil-Waututh are the People of the Inlet and have used, occupied and governed the lands and waters of Burrard Inlet and surrounding watersheds since time immemorial. It is the birthright, obligation and sacred trust of the Tsleil-Waututh to care for and restore this environment to a state of health and balance. The Tsleil-Waututh people have noticed the complex impacts of climate change in their territory for decades. With an inherent understanding of how climate change is affecting the environmental and its cultural values, the Nation has passed down stories, traditions and knowledge-sharing that are the living record of this information. The Tsleil-Waututh Nation has continuously adapted and enhanced community resilience throughout time.

The Tsleil-Waututh are particularly concerned about the acceleration of harm to the environmental, cultural, spiritual and economic values of the Nation. Waterflow regime changes to local creeks, rising sea levels, and increased bank and coastal erosion are affecting the reserve land area, associated economic opportunities and real estate developments, while hotter and drier summers are threatening forest-based habitat, biodiversity, and cultural and recreational use areas. The Tsleil-Waututh worry about the spread of invasive species, soil degradation and landslides in the Indian River Watershed—the heart of the Nation. The health and abundance of salmon, forage foods, wildlife and cultural use areas are at risk.

Acknowledging the immediacy and intensity of climate change, Tsleil-Waututh members are developing a Community Climate Change Resiliency Planning Process (CCCRP). The CCCRP aims to build understanding of the impact of climate change hazards on the Tsleil-Waututh community, to institutionalize climate resiliency planning through Tsleil-Waututh's government, and to develop adaptation strategies for future prioritization and implementation to ensure that current and future generations of Tsleil-Waututh people can continue to thrive in a changing climate.

As a multi-year undertaking, the CCCRP assesses Tsleil-Waututh climate vulnerabilities, develops an action plan with prioritized adaptation strategies, and supports implementing these adaptation strategies while monitoring their effectiveness. At the beginning of this work, the Tsleil-Waututh undertook an extensive hazard mapping and exposure sensitivity analysis, assessing the associated vulnerabilities on the lands, people, and culture of the Tsleil-Waututh Nation on and near the lands of Tsleil-Waututh Reserve IR#3.

The Tsleil-Waututh's unique eco-cultural and archeological approach to hazard mapping has revealed previously unknown climate information. Subsurface testing identified intact charcoal-rich sands and fire-altered rock dating back more than 3,000 years that, while originally situated on land, are now located well into the marine intertidal area. Cross-referencing the archaeological findings with oral history accounts from Elders of the Tsleil-Waututh Nation, the archaeology team identified areas where foreshore lands have receded (up to 12 m in some places) as a result of shoreline erosion. With archaeological clam shell samples, the Nation is considering exploring the use of isotopic oxygen analysis in combination with carbon dating, in order to shed light on historical oceanic conditions and temperatures, and potential impacts to the Tsleil-Waututh way of life.

The CCCRP is a culturally and locally relevant strategy in building resilience to current and potential future impacts of climate change. The CCCRP is a manifestation of Tsleil-Waututh stewardship and sacred obligation to care for the lands, waters and air, in acknowledgement of our changing climate.

2.7 Cities and towns are moving from adaptation planning to implementation

Implementation of adaptation initiatives by cities and towns is not keeping pace with the risks posed by current weather extremes and future climate changes. However, examples of implementation are becoming more common, and the barriers to action are being reduced. Promising practices like mainstreaming and innovative funding arrangements offer opportunities to scale up and accelerate implementation.

Although adaptation planning has been progressing quickly in cities and towns, adaptation implementation has been slower to advance due to a variety of barriers. These barriers are generally well understood, and relate to financing, decision-support tools, competing priorities, governance and professional silos. A number of emerging strategies to address these barriers are likely to accelerate the transition from planning to implementation. These include the creation of adaptation plans that explicitly focus on implementation, mainstreaming of adaptation into existing operations, practices and planning within local governments (e.g., incorporating climate risks into asset management), and the inclusion of First Nations, Métis and Inuit peoples in the design and implementation of climate change adaptation initiatives.

2.7.1 Introduction

Awareness of the need to adapt to climate change is no longer a significant barrier; tools for assessing vulnerability and risk are increasingly available, and adaptation plans and strategies are now common (*see* Box 2.6; Federation of Canadian Municipalities, 2019; McMillan et al., 2019; Moghal et al., 2017). There is also evidence of implemented actions (*see* Case Story 2.6) and novel policies. For example, the Canadian Institute of Planners' policy on climate change planning "envisions a future in which Canadian communities are planned, designed, developed, and managed to contribute to climate stability and to be more resilient in the face of unavoidable changes in the climate, and in the process, to become more liveable, prosperous, and equitable" (Canadian Institute of Planners, 2018, p. 3). However, adaptation implementation in cities and towns has not kept pace with increasing climate risks in Canada (ICLEI Canada, 2016), nor has it in other counties (e.g., Woodruff and Stults, 2016). There is a tendency to overestimate the capacity of adaptation planning to deliver the intended outcomes of adaptation (Mimura et al., 2014), and so, the increasing prevalence of adaptation planning in Canada's cities and towns is not an appropriate indication of implementation. Implementation remains the primary challenge for cities and towns seeking to adapt to climate change.

2.7.2 Barriers to adaptation

A number of barriers make it difficult to implement adaptation. The barriers presented in Table 2.3 are drawn from Canadian and international literature, and vary in their extent across Canada. If they are understood and considered early on, many of the barriers discussed below can be overcome (ICLEI Canada, 2016). Where appropriate, these efforts should consider multiple barriers simultaneously (Hamin et al., 2014).

Table 2.3: Common barriers to adaptation

CHALLENGE/BARRIER	DESCRIPTION
Financing	• Conflicting incentives when municipal revenue is contingent on development (e.g., property tax, development cost charges) • Funding largely limited to large-scale infrastructure projects, which favour larger cities • Limited innovative financial models (e.g. green/resilience bonds, cost-sharing schemes, public-private partnerships) • Public opposition to innovative approaches to financing adaptation
Uncertainty	• Inherent uncertainty associated with using future conditions to make decisions • Lack of perceived immediacy of climate change consequences • Strategic and institutional uncertainty
Data and tools	• Limited economic studies on costs of damages of climate change impacts • Limited economic studies or cost-benefit analyses for adaptation • Lack of higzhly context-specific data • Too many tools and frameworks resulting in information overload • Few tools to specifically support the implementation of adaptation initiatives • Limited guidance and tools that support community engagement on adaptation
Governance	• Federal departments are politically limited in direct transfer payments to local governments, requiring coordination and relationships with provincial governments and/or third parties (e.g., FCM) • Disconnect between needs of local action and provincial policy/legislation • Limited enabling conditions, such as mandates, policy, regulations, standards and guidelines

CHALLENGE/BARRIER	DESCRIPTION
Governance (continued)	• Limited political will, motivation, willingness to act and belief that action will be effective Limited jurisdictional power over private property • Limited coordination with private sector and property owners, as well as vulnerable groups • Limited public support and insufficient level of services for the current demand • Lack of non-environmental considerations in adaptation
Human resources	• Limited internal capacity, combined with limited national mandates and definitions of adaptation • Limited collaboration across professional associations • Compartmentalization and institutional fragmentation

Sources: BC Auditor General, 2018; Dohertyet al., 2016; ICLEI Canada, 2016; Nordgren et al., 2016; Adaptation to Climate Change Team, 2015; Biesbroek et al., 2015; Eisenack et al., 2015; Environmental Commissioner of Ontario, 2015; Ford and King, 2015; Archer et al., 2014; Moser, 2014; Pahl et al., 2014; Toman, 2014; Hallegatte and Corfee-Morlot, 2011; Mees and Driessen, 2011; Burch, 2010.

2.7.3 Advancing adaptation implementation

There are many tools and resources that support adaptation planning (e.g., planning guides—*see* Figure 2.15, FCM's staff support grants, Canadian Centre for Climate Services Support Desk). These include tools and resources that support implementation, including guidance on designing implementation schedules and mechanisms, and best practice case studies (ICLEI Canada, 2016). It is important that adaptation-planning processes consider implementation (e.g., City of Barrie, 2018; Zukiwsky et al., 2016). Implementation-ready plans address issues such as feasibility, resources, accountability, partnerships, authority and interaction with other initiatives (Ontario Centre for Climate Impacts and Adaptation Resources, 2015) and emphasize "no-regrets" options that address one or more climate hazards, in addition to non-climate issues that are priorities for the local government (Chen et al., 2016). Focusing explicitly on implementation can help to ensure that plans reach their aspirational outcomes (e.g., reducing risk to people and property), especially if the initiative is an area of high public concern, and there are clear cost implications (Picketts, 2015).

Figure 2.15: The traditional adaptation planning process (steps 1–6), with enabling actions added. Source: Adapted from City of Vancouver, 2018.

Rather than developing new or stand-alone plans and strategies, many cities and towns are incorporating climate change considerations into a wide array of municipal operations, policies, plans and services, including infrastructure decisions, asset management, official community plans and land-use plans, capital plans, master plans and emergency management frameworks (City of Vancouver, 2018). Mainstreaming of climate change adaptation into existing frameworks and operations is an efficient strategy to overcome implementation barriers, such as insufficient human and financial resources, lack of momentum and competing priorities (ICLEI Canada, 2016). This strategy is more effective when accompanied by efforts to build and maintain internal capacity (Picketts, 2015), and to create forums for collaboration across jurisdictional boundaries (Adaptation to Climate Change Team, 2017).

Climate change adaptation requires coordination among broad partner networks (Rosenzweig and Solecki, 2018). Collaborative forums provide municipal representatives who have implemented climate adaptation initiatives with the opportunity to share their experience (i.e., peer-to-peer learning). For example, municipalities in Quebec are looking for implementation examples from similar cities and towns (Bleau et al., 2018). An example of a program that seeks to facilitate this type of collaboration is the University of British Columbia's Resilient-C project that enables communities to share knowledge and resources to support coastal hazard risk reduction (Resilient-C Research Team, 2020). Similarly, FCM's Climate Adaptation Partnership Grants have resulted in projects that leverage non-profit expertise to enable groups of cities and towns to collaborate; such an approach also supports the scaling up of action.

Box 2.6: Benchmarking adaptation activity in Canadian cities

Between 2004 and 2014, most of the adaptation activity in Canada was occurring at the municipal level, with the majority of this work involving planning and capacity building, but few examples of implemented initiatives (Eyzaguirre and Warren, 2014). A number of surveys provide insight into the state of play of adaptation in Canada's cities and towns. The 2018 Local Adaptation in Canada survey, carried out by the Federation of Canadian Municipalities (FCM), the University of British Columbia and the University of Waterloo, found that more than half of the 180 local governments respondents had initiated formal adaptation planning discussions in their community within the last four years (McMillan et al., 2019). These discussions are being advanced by a range of municipal departments, but are still sometimes ad hoc and reactive (*see* Figure 2.16), and often do not result in implementation due to a lack of human and financial resources (McMillan et al., 2019). This survey builds on a similar survey delivered in 2012 as part of the National Municipal Adaptation Project (National Municipal Adaptation Project, 2014), though direct comparisons between the two surveys are not possible due to differences in survey questions and methodology (McMillan et al., 2019).

A Climate Adaptation Maturity Scale was developed by FCM to facilitate the self-assessment of a municipality's institutional readiness and progress in adapting to climate change. The scale helps municipalities and FCM to rapidly self-assess their current state, as well as to identify areas of potential improvement across three competency areas, as they relate to climate change adaptation: 1) policy; 2) human resources and governance; and 3) technical and risk management capacity (Federation of Canadian Municipalities, 2017). It uses the following population categories: small (< 10,000), medium (10,000–100,000) and large (> 100,000). Based on the results from 110 ongoing adaptation projects, it was found that larger cities have higher baseline capacity in the policy and human resources and governance dimensions (Federation of Canadian Municipalities, 2019). Municipalities will be invited to do a second self-assessment following the completion of their project. The results from 16 completed projects (*see* Figure 2.16) show that, even though projects undertaken by large municipalities end with a higher competency level in all three areas, small and medium-sized municipalities also show a significant progression on aspects of adaptation during their project.

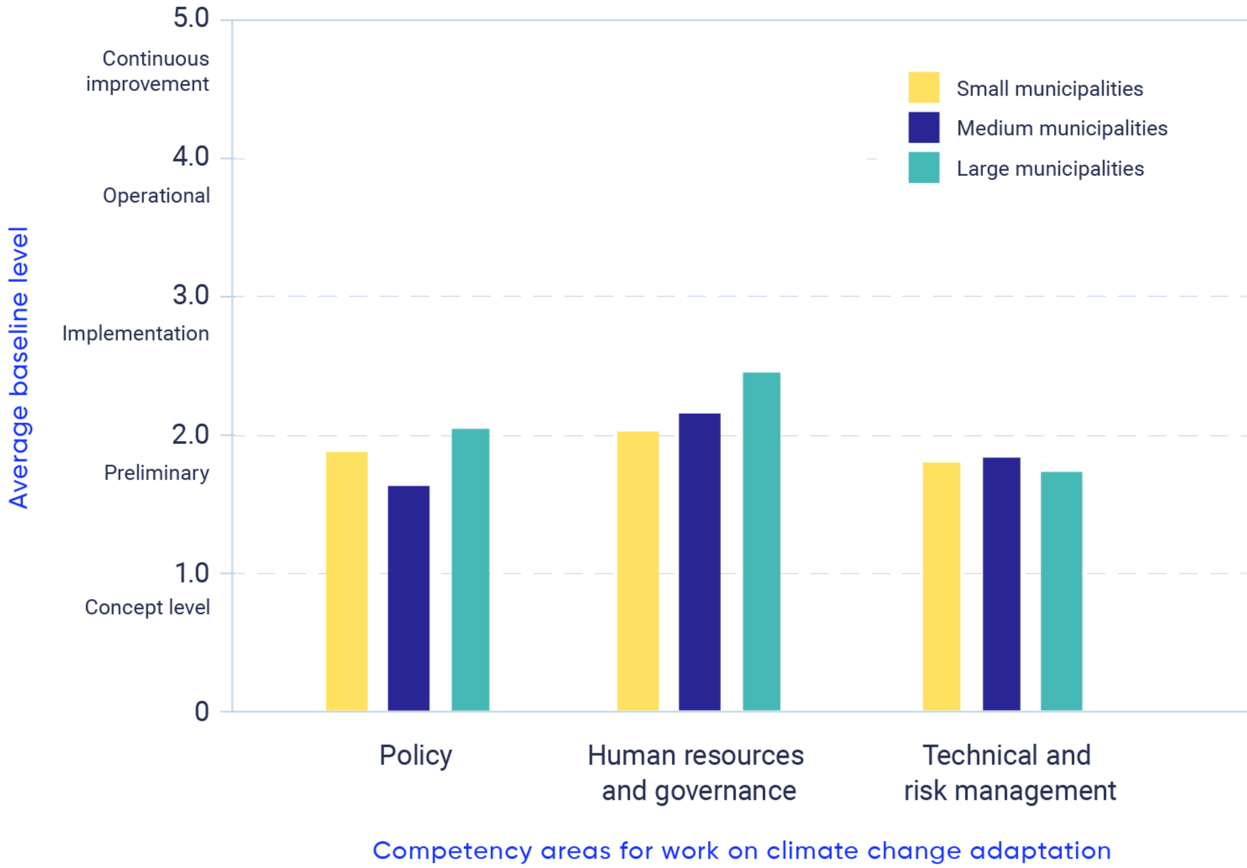


Figure 2.16: Graphical representation of baseline self-assessments made using FCM's Climate Adaptation Maturity Scale provided by municipalities that received FCM-support towards local adaptation projects. The five-point scale ranges from 1.0 (concept level) to 5.0 (continuous improvement level), and includes three competency areas: 1) policy, 2) human resources and governance, and 3) technical and risk management. This graph shows the average self-assessment values provided by small municipalities (e.g. less than 10,000), medium-size municipalities (e.g. 10,000-100,000) and large municipalities (e.g. more than 100,000) at the start of their adaptation projects. Data source: Federation of Canadian Municipalities, 2019.

A 2019 landscape assessment and needs analysis conducted by FCM and Environment and Climate Change Canada scanned highest-order planning documents (e.g., official community plan) for 732 local governments for evidence of a commitment to climate change adaptation. This scan revealed that 19% of the municipalities demonstrated a commitment to climate change adaptation, 58% showed no commitment, and 23% had no high-order planning document available online (Federation of Canadian Municipalities and Environment and Climate Change Canada, 2019). Of those that had made commitments, 28% were in Ontario, 25% in British Columbia, and 10% from each of Alberta and Quebec. A secondary scan of 120 local governments revealed that a commitment to climate change by larger municipalities (>50,000) tended to be in a stand-alone adaptation or in resilience plans, whereas for smaller municipalities, if references to climate change were present, they were in broader sustainability or community development plans. This finding is supported by additional research in the Canadian context (Moghal et al., 2017).

The above findings focus largely on capacity building and planning, and do not represent a significant departure from those reported in the 2014 assessment (Eyzaguirre and Warren, 2014). Although there is evidence of more widespread implementation, the above surveys do not provide sufficient insight into the extent and nature of implemented adaptation initiatives in Canada. Despite this shortcoming, the surveys discussed above represent a relatively rich, albeit fragmented, source of baseline data for future research and assessments, and provide a useful point of comparison. It should be noted that there are also international surveys (e.g., Aylett, 2015; Carmin et al., 2012) and surveys conducted by industry associations (e.g., Canadian Institute of Planners, 2019) that contain some element of the climate change adaptation state of play in Canadian cities and towns, although these are less relevant for this chapter.

Case Story 2.6: Adaptation measures and co-benefits through the upgrading of Rue Saint-Maurice in Trois-Rivières, QC

Trois-Rivières, Quebec, is a riverside city with a population of 134,410. The City has had a climate change adaptation plan since 2013 (SNC-Lavalin Environnement, 2013) and has participated in two PIEVC (Public Infrastructure Engineering Vulnerability Committee) assessments (Osseyrane and Kamal, 2013; Rivard et al., 2013). A significant adaptation intervention that resulted from the plan is “Le Grand Projet de la Rue Saint-Maurice,” which involved significant upgrades to a 1.3-km stretch of residential road (Ville de Trois-Rivières, 2018). The project used a combination of built and natural infrastructure, and aimed to reduce the urban heat island effect, increase the presence of plants, beautify the landscape, improve neighbourhood safety for pedestrians and motorists, and to help replenish the water table with drinking water through sound stormwater management (*see* Figure 2.17; Ville de Trois-Rivières, 2018). Parking spaces along the street have been replaced by more than 135 trees, 1,000 shrubs and 18,000 plants. The project also had a significant built infrastructure component, including the installation of 5.05 km of pipes and 103 sumps to manage the stormwater not absorbed by the green infrastructure.

Figure 2.17: An overview of the adaptation and GHG emissions reduction measures implemented through the upgrading of Rue Saint-Maurice in Trois-Rivières, QC. Photo courtesy of Ville de Trois-Rivières.

Monitoring and evaluation data for this project is not yet available, but will be once the project has been completed. It is expected that a research team will collect pre- and post-intervention data relating to peak flow, water volume, infiltration and water quality parameters (Ouranos, 2017). The project was funded primarily by the Fund for Drinking Water and Wastewater Treatment, and there are plans to conduct similar projects elsewhere in Quebec once the pilot has been evaluated.

2.8 Monitoring and evaluation of adaptation is an important and often overlooked step

Monitoring and evaluation methods are required to track adaptation progress, and measure whether adaptation efforts are resulting in their desired outcomes. While promising approaches exist, monitoring and evaluation of adaptation projects and outcomes are still rare, and there is value in helping cities and towns to develop approaches that are effective and comprehensive.

Although there has been considerable conceptual work on monitoring and evaluation (M&E) of adaptation, it remains difficult for cities and towns to apply this step. This is partly due to the fact that the adaptation field in Canada is just beginning to enter the implementation phase in a significant way. It is likely that this transition will spur the advancement of M&E approaches that cities and towns can use to overcome inherent difficulties, including shifting baselines, and attribution and resource requirements. M&E approaches work best when they reflect who is benefitting from adaptation, and when they embed accountability into the outcomes of investments in adaptation, take multiple co-benefits into account, and enable course corrections. Operationalizing adaptation monitoring and evaluation for specific contexts will be an important area of practice in the near term.

2.8.1 Introduction

As cities and towns across Canada begin to move from adaptation planning to implementation, there is an urgent need for monitoring and evaluation (M&E) approaches that can be used to identify baseline conditions, guide action, track progress and evaluate the extent to which adaptive capacity and/or resilience are being achieved. The adaptation M&E imperative operates across all scales. Calls for M&E can be seen in the Paris Agreement (Ford et al., 2015), Sendai Framework for Disaster Risk Reduction, Pan-Canadian Framework on Clean Growth and Climate Change, provincial adaptation plans (BC Auditor General, 2018), and at the local level. There is a strong literature base offering guidance on adaptation M&E (e.g., Brown et al., 2018; Leagnavar et al., 2015; Bours et al., 2014; Dinshaw et al., 2014; Pringle, 2011; Jacob et al., 2010), in addition to strong proxy literatures (e.g., disaster resilience, program evaluation, risk management). However, translating usable indicators and approaches from this literature is likely to be difficult for cities, especially those with limited capacity.

2.8.2 Progress and approaches

There are several practical examples of adaptation M&E in Canada. One of the most salient is ICLEI Canada's Building Adaptive and Resilient Communities (BARC) program, which is a participatory planning framework for climate adaptation that requires consideration of M&E. This requirement has led to a number of Canadian adaptation plans that incorporate proposed indicators, but no formal monitoring and evaluation strategies to date (e.g., City of Vancouver, 2012, p. 54). A more regional example of adaptation indicators in the Canadian context can be seen in the Columbia Basin Trust's "State of The Basin" indicators (Columbia Basin Trust, 2015). The City of Surrey, BC, uses a series of sustainability and adaptation indicators to display progress and to encourage action (*see* Case Story 2.7).

In 2018, Environment and Climate Change Canada convened an Expert Panel on Climate Change Adaptation and Resilience Results (EPCCARR) that developed a series of indicators—structured around the five key focus areas in the adaptation pillar of the Pan-Canadian Framework—that could be used to measure progress on adaptation (EPCCARR, 2018). These include process and outcome indicators, many of which refer to measurable developments at the local government or community level (e.g., number of days of disruption to basic services and critical infrastructure). Potential challenges for mobilization of EPCCARR indicators at the city-level M&E include the lack of relevant data, and the fact that data are not organized in ways that might be useful for M&E processes (EPCCARR, 2018). Training and technical assistance on data collection and organization would facilitate consistent M&E application.

There are several international resilience planning frameworks that include M&E guidance for cities. The largest of these is UNISDR's Resilient Cities and the City Resilience Framework, with the accompanying City Resilience Index, associated with the Rockefeller Foundation's 100 Resilient Cities program. The City Resilience Index measures relative performance over time, rather than creating comparisons between cities, and provides indicators and metrics that can be used as a common basis for monitoring and evaluation, to create benchmark comparisons with other cities, and that are meant to identify areas of weakness and to suggest actions that can improve resilience (ARUP and Partners, 2016). Similarly, the Climate Risk and Adaptation Framework and Taxonomy (CRAFT) is a decision-support tool that relies in part on process indicators to demonstrate progress internally and in relation to other cities (C40 Cities, 2016). However, neither of these approaches was developed with the active participation of Canadian cities, and they have limited applicability in the Canadian context, as their primary focus is on the largest cities.

There are also M&E frameworks that do not include the use of indicators. For example, outcome harvesting uses program documents and interviews to quantify progress on projects (Eyzaguirre, 2015; Wilson-Grau, 2015). This approach can help overcome some of the challenges related to data availability and organization described above. However, other challenges still remain. Many adaptation initiatives are not initially labelled as such (i.e., unintentional adaptation), and are therefore not included in M&E reporting, even though they contribute to reducing vulnerability (Hughes, 2015). For example, the installation of larger culverts may have been motivated by analysis of historical trends, rather than influenced by a changing climate.

Adaptation also occurs over long timelines, whereas project outcomes need to be evaluated over the course of decades, and often only after an extreme event has occurred (Moser and Boykoff, 2013). There are also challenges associated with attribution. Cities and towns are complex systems, and it can be difficult to disentangle causal pathways such that an outcome (e.g., reduced flood damage) can be attributed to an adaptation intervention (e.g., investment in green infrastructure). Similarly, successful adaptation often means measuring avoided impacts (e.g., fewer hospital visits during a heat wave) (Bours et al., 2014). Finally, articulating the co-benefits associated with adaptation initiatives is another significant challenge faced by those developing climate adaptation M&E plans.

The selection of an M&E approach should take into account its appropriateness for the context, and its capacity for precision and accuracy, explanatory power and utility (Constas, 2015). Monitoring and evaluation plans are most effective when they are created early in the planning process, and used to communicate results and harmonize action and reporting across municipal departments and with external stakeholders (ICLEI Canada, 2016). It is also important that M&E be designed and accomplished in a participatory way (Sharifi, 2016; Villanueva, 2011). As Moser and Boykoff (2013, p. 3) write, "Success is not simply to be decided on scientific, rational, objective, or procedural grounds, but is in important ways normative, historically contingent, and context-specific." For example, including various perspectives—Indigenous, gender, business, marginalized populations—in the design of M&E frameworks can ensure that resilience objectives are mutually agreed upon and equitable (Doorn, 2017; EPCCARR, 2018). This will require creative development of engagement approaches, as well as expanded educational tools and resources.

Case Story 2.7: Tracking progress on adaptation through the City of Surrey's Sustainability Dashboard

The City of Surrey is a coastal city in British Columbia with a population of 517,885. For over eight years, the City has been using a Sustainability Dashboard to communicate progress on items relating to its Sustainability Charter, which addresses the following themes: inclusion, built environment and neighbourhoods, public safety, economic prosperity and livelihoods, ecosystems, education and culture, health and wellness, and infrastructure. The dashboard is updated annually—except where reliant on census data—and, although it is explicitly focused on sustainability, there are several indicators that report on data relevant to climate change adaptation (e.g., shade trees planted on public property, extent of green infrastructure network). Some of the indicators also display links that encourage individuals to take action. For example, the indicator page for the number of trees planted on public property contains a link explaining how residents can add to Surrey's urban forest.

Surrey is involved in the development of World Council for City Data's ISO 37123 for Resilient Cities, and plans to explore how these indicators could be integrated into the dashboard in the future. In 2016, the City of Surrey was certified as a World Council for City Data's ISO 37120 Platinum Certified City. However, the decision about which adaptation and/or resilience indicators to report on has not been straightforward. Surrey's 2013 Climate Adaptation Plan contains 36 proposed indicators relating to the action items from the plan (City of Surrey, 2013). An internal study has concluded that some of these indicators are no longer appropriate, while others are weakened by lack of data availability and accountability, as well as other factors. However, most importantly, the City is currently transitioning towards a data-driven decision-making (D3M) approach that seeks to harmonize data collection and reporting across all city departments and initiatives. The outcomes of this process will help the City to determine which adaptation-related data to collect, and will also drive the creation of a new public-facing dashboard that uses a contemporary interface and data management system (e.g., Power BI), instead of the bespoke dashboard created for the city in 2011.

2.9 Moving forward

2.9.1 Knowledge gaps and research needs

As the climate change adaptation field matures in Canada, there is a need for conceptual and practical guidance in a number of areas. First, decision-makers across Canada would benefit from more explicit guidance on how to mainstream adaptation into existing workflows (e.g., master planning processes) and business practices (e.g., procurement, financing and project management). This would help cities and towns to embed adaptation across the organization, which would likely strengthen implementation.

There is a strong demand for research findings and methodological guidance relating to the quantification of economic, as well as social and environmental costs of climate impacts. These analyses can support compelling projected returns on investment for adaptation projects. There is also a demand for cost benefit analyses that can be applied to adaptation initiatives (Bleau et al., 2018). The Costs and Benefits of Climate Change Impacts and Adaptation chapter in this assessment represents a significant step forward in addressing this need.

The adaptation field itself could be the subject of future research. An assessment of the climate change adaptation field in the United States was guided by the following question: "What would a strong, mature adaptation field look like, and what would it take to build it?" (Moser et al., 2017, p. 8). Such a study in Canada could help to more clearly articulate the role that cities and towns play in adapting to climate change, and how they could be supported by others as the field matures and as adaptation initiatives become more common. Similarly, although frameworks that evaluate plan quality are common (Guyadeen et al., 2019; Dokoska et al., 2018), research that examines the quality of adaptation plans is only beginning to emerge (e.g., Woodruff and Stults, 2016).

2.9.2 Emerging issues

It is expected that several issues of relevance to cities and towns will emerge in the adaptation field in the coming years. One such issue relates to determining the appropriate relationship between climate change adaptation and resilience. Although inconsistently defined (Meerow et al., 2016; Meerow and Stults, 2016), the concept of resilience applied in the urban context often connotes a broad scope that includes non-climatic stressors like lack of affordable housing, economic downturns, or decreasing populations, such as those observed in Quebec and eastern Canada (Statistics Canada, 2017d). Although the concept of resilience can encourage local governments to govern collaboratively across disciplines, thereby taking more of a systems approach, and to consider the desirable qualities of resilient systems (e.g., flexibility, redundancy), this concept can be challenging to apply in practice, as it adds complexity to the already complex endeavour of adapting to climate change. Navigating this discursive and practical terrain is an emerging issue in the field of climate change adaptation in Canada, where an increasing number of cities are issuing requests for proposals for climate resilience strategies.

This chapter has highlighted some of the emerging issues related to Indigenous peoples and climate change adaptation in cities and towns. The inclusion of Indigenous people in planning and implementation processes within and adjacent to cities and towns is an emerging area of practice. Similarly, First Nations, Métis and Inuit communities and scholars have stressed the importance of considering Indigenous Knowledge Systems in addition to Western science when addressing climate change (EPCCARR, 2018). The inclusion of the processes and products of Indigenous Knowledge Systems into adaptation planning and implementation is likely to be an emerging priority in the Canadian adaptation field.

The appropriate and effective inclusion of social equity into climate change adaptation planning and implementation processes is another emerging issue facing decision-makers in cities and towns. Considering equity issues is thought to increase adaptive capacity and well-being in cities (Rosenzweig and Solecki, 2018), and can increase the likelihood of adaptation implementation (Gonzalez et al., 2017), although this has not been explored empirically in Canada. It is increasingly acknowledged that an equity lens should be applied during adaptation planning and implementation, but conceptual and practical guidance on applying this lens is generally lacking, especially in small and medium-sized cities and towns.

The declaration of climate emergencies has also emerged as a practice by many cities and towns across Canada. (Climate Emergency Declaration, 2020). The objective of the climate emergency declaration is to highlight that unless governments acknowledge and publicly declare climate change as the utmost global emergency, sufficient and profound action will not take place. Since climate emergency declarations are intended to encourage action on mitigation and adaptation, they are likely to be an important component of the adaptation landscape in Canada in the coming years.

Another emerging issue faced by adaptation practitioners in Canada is the need to connect adaptation with greenhouse gas mitigation efforts. This approach is increasingly referred to as low carbon resilience (LCR) (Nichol and Harford, 2016). LCR has strong relevance at the local government level, with particular emphasis in the areas of asset management and corporate strategic planning (Adaptation to Climate Change Team, 2019). Discussion of this approach is emerging in the literature (IPCC, 2018), and practical application is being researched in the local government context, where it is being shown to have multiple co-benefits in terms of health, equity, biodiversity and other key areas (Shaw et al., 2019) and is also occurring in the building sector. For example, the US Green Building Council's RELi standard provides guidance on LCR approaches, and there is a strong push to design or retrofit buildings for low carbon resilience (BOMA Canada, 2019; Bristow and Bristow, 2017).

There are also emerging issues that relate to continued technological development in cities and towns. The National Research Council of Canada identifies capabilities in smart infrastructure and cities of the future as a key opportunity for Canada (National Research Council of Canada, 2019). It is essential that efforts to create smart cities take into account the need to adapt to climate change. For example, self-driving cars could unlock tremendous potential for green infrastructure, including through the conversion of existing road infrastructure to more permeable surfaces that support stormwater management. There are similar opportunities relating to the role of big data (Ford et al., 2016) and artificial intelligence.

2.10 Conclusion

Canada's cities and towns will continue to be affected by climate change. Although the extent of these impacts remains unclear, early action is required to minimize the extent of negative impacts and to leverage the opportunities associated with positive impacts. As shown in Box 2.6, Canada's cities and towns continue to make progress on adaptation to climate change, and the field is entering the era of implementation. While much of this implementation is reactionary, strategic and proactive implementation is beginning to emerge. With a concerted, supported and well-informed effort, implementation is likely to increase the adaptive capacity and resilience of cities and towns in the future.

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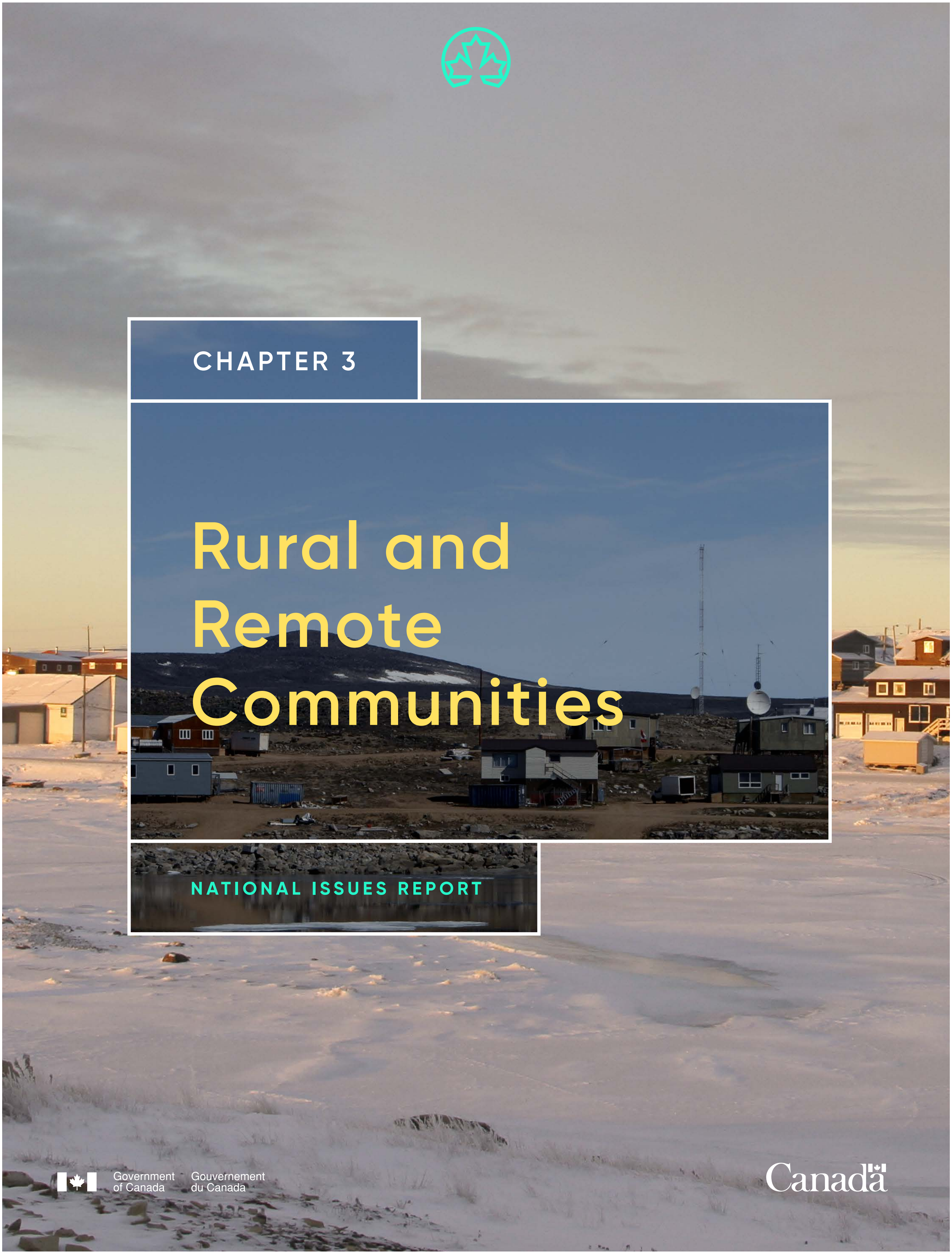

CHAPTER 3

Rural and Remote Communities

NATIONAL ISSUES REPORT

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Key messages

Climate change is affecting rural and remote communities (*see* Section 3.2)

Rural and remote communities often experience environmental, social, economic, cultural and health impacts from climate change disproportionately compared with urban centres. Despite these challenges, rural and remote communities display strong resilience and are often at the forefront of adaptation action in Canada.

Local and Indigenous Knowledge are key to adaptation and understanding climate impacts (*see* Section 3.3)

Residents of rural and remote communities have a strong connection to the environments that they depend on for their livelihood, sustenance, well-being and way of life. Place-based knowledge systems, including local and Indigenous Knowledge, and lived experience are key to understanding and adapting to climate change impacts in rural and remote communities and areas.

Climate change is challenging livelihoods and economies (*see* Section 3.4)

Climate change is already impacting many of the economic sectors and subsistence activities that rural and remote communities rely on for their livelihoods and economic well-being. Local adaptation strategies are helping to protect traditional economies through planning and capacity building, changing land practices and use of technology.

Critical infrastructure and services are at risk (*see* Section 3.5)

Critical infrastructure and related services, particularly in rural and remote coastal communities, are at risk of failure and disruption from increases in the number and severity of extreme weather events. In response, a growing number of these communities are mainstreaming climate change considerations into community planning and design, and are beginning to reimagine, reinforce and rebuild their built environments.

Individual and community health and well-being are being negatively affected (*see* Section 3.6)

In rural and remote communities, health and well-being are strongly influenced by social, cultural and physical environments. Climate change is negatively impacting the health and well-being of individuals and communities, both directly and indirectly. Reducing risk, adapting to climate change impacts and realizing co-benefits from GHG emissions reduction present important opportunities for the health sector.

Climate change is resulting in intangible losses and damages (*see* Section 3.7)

Climate change impacts are leading to a wide range of intangible losses and damages in many rural and remote communities and areas, including the loss of identity, cultural continuity and sense of place. These intangible losses and damages are expected to be widespread and cumulative, and are critical to consider in climate change adaptation and policy.

Local participation in adaptation decision-making improves outcomes (*see* Section 3.8)

Enhancing governance capacity and decision-making related to climate change adaptation in rural and remote communities requires access to additional resources, information and support. Decision-making processes related to adaptation programs and policy can be made more effective through greater participation of local residents and organizations, inclusion of local and Indigenous Knowledge, and consideration for the specific circumstances of rural and remote communities and areas.

3.1 Introduction

There are rural and remote areas in every province and territory across Canada, with many remote communities located in Arctic and Subarctic parts of the country. These areas, and the communities located within them, are home to residents, businesses and organizations that are often highly dependent on natural resources and ecosystems for cultural purposes, livelihoods, transportation and well-being. Compared to urban centres, rural and remote communities often experience greater impacts from climate change, particularly in the Arctic and Subarctic regions where changes in climate are occurring more rapidly than elsewhere in the country (Bush avnd Lemmen, 2019). These communities also tend to have fewer financial, human and formal institutional resources with which to respond to these changes. At the same time, however, rural and remote communities have access to important assets that support resilience and adaptation from which they can draw, such as strong informal economies, social networks and connections to place, community and culture.

The challenges and inequities in rural and remote regions (*see* Box 3.1) impact all people living in Canada. While Canada's 15 largest municipalities are home to 53% of Canada's population, the vast majority (79%) of Canadian municipalities and other settlements are located outside of major metropolitan areas (Minnes and Vodden, 2019; Statistics Canada, 2016). Furthermore, nearly 6 million Canadians (approximately 17% of the country's population) live in rural and remote areas[1] (Statistics Canada, 2016).

Box 3.1: Rural and remote communities

For the purpose of this chapter, rural and remote communities (including small towns) are defined as having a population of fewer than 10,000 people. In rural communities, less than 50% of the population commutes to an urban location for work. Remote communities either have no residents that commute to an urban location for work or are located in the Yukon, Northwest Territories, Nunavut, Nunavik or Nunatsiavut[1].

Rural and remote communities make critical contributions to Canadian society, culture and environmental stewardship. These regions provide natural resources such as food, energy and drinking water, as well as other ecological amenities (*see* Ecosystem Services chapter) that support all Canadians, while also generating approximately 30% of Canada's gross domestic product (Vodden et al., 2019). Despite these

1 A variety of definitions for rural and remote communities are used throughout the literature; the definition used in this chapter was selected to maintain consistency with the Cities and Towns chapter. Given the importance of rural-urban interactions and interdependencies for rural lives and livelihoods, this definition includes all settlements located outside of Statistics Canada Census Agglomeration and Census Metropolitan areas (e.g., outside of "urban" areas) (Statistics Canada, 2016). In contrast, Statistics Canada's current classification of population centres identifies small population centres as those with populations of 1,000–29,999 (Statistics Canada, 2016).

contributions, rural and remote communities in Canada remain comparatively under-researched and have not been prioritized in terms of policy development and funding (Canadian Rural Revitalization Foundation, 2015). This chapter discusses the gaps in research and policy from a climate change perspective by assessing the current knowledge of climate change impacts, adaptation strategies and potential future directions for climate change adaptation in rural and remote areas.

3.1.1 Rural and remote Canada

Despite the wide geographic distribution of rural and remote communities in Canada, they share similar characteristics that influence and mediate their experiences with climate change. For example, rural and remote communities are often geographically isolated; reliant on natural resources for sustenance, livelihoods, and ways of life; and have limited social and physical infrastructure and capacity (e.g., limited access to technology and communication systems, health and education services, supplies, and human resources). At the same time, rural and remote communities often have strong social capital and networks, extensive local and/or Indigenous Knowledge, and high rates of community involvement, which create resiliency and pride (Lemmen et al., 2008). It is important to note that while there are shared priorities, concerns and strengths, rural and remote communities across Canada display a wide diversity of important factors and attributes, including physical geography, culture, economy and demographics. Such factors differentially affect the experiences, responses and capacities of these communities related to climate change impacts and adaptation.

Climate-related changes are occurring alongside other social and economic changes in rural and remote communities, leading to social disruption. Compounding stressors include the adoption of labour-saving technologies to lower production costs in resource industries, and changes in market conditions and international competitiveness due to shifts in global economic policy, such as the expiration of the Softwood Lumber Agreement in 2015 or the 2010 European Union ban on seal skins (Schroth et al., 2015; Reed et al., 2014). New technologies, the rising cost of living, and a growing wage economy in some communities also intersect with climate-related changes and impacts on land-based subsistence activities (Clark et al., 2016b; Pearce et al., 2015).

Other changes compounding the ways in which climate change is experienced in rural and remote communities in Canada include demographic changes (e.g., ageing populations), population growth in many Indigenous communities, and the movement of young adults and retirees to amenity-rich locations. These changes can have negative implications on the rural labour force and available tax base, services and business opportunities, social dynamics, transmission of intergenerational knowledge, and virtually all aspects of community life. From an institutional perspective, rural and remote areas are often disproportionately affected by reductions in government funding for programs and services, and are subject to province- or territory-wide policies that are not well suited to their particular circumstances (Vodden et al., 2019; Dampier et al., 2016). For example, residents of these areas often experience disproportionately more job losses and negative economic consequences resulting from changes to province- or territory-wide energy policy (Dampier et al., 2016). These challenges, combined with frequently changing circumstances, require support at all levels (national, regional, local) to develop and implement strategies for coping, adaptation and resilience in rural and remote areas. Figure 3.1 highlights assets and challenges for rural and remote communities related to climate change adaptation.

Figure 3.1: Summary of key assets and challenges for rural and remote communities and areas related to climate change adaptation.

3.1.2 Approach to chapter development

Building on past national assessments (Warren and Lemmen, 2014; Lemmen et al., 2008), this chapter synthesizes the state of knowledge on the impacts of climate change in rural and remote communities across Canada. Specifically, this chapter applies a social equity lens to climate and environmental changes, and emphasizes adaptation, strength and resilience in rural and remote communities. While responses at all levels are required, this chapter emphasizes the need for local strategies that are culturally and geographically relevant. Information and perspectives from all provinces and territories in Canada are presented in this chapter. The information included was gathered through a systematic review of published peer-reviewed and broader literature related to climate change in rural and remote communities and areas across Canada; consultation with individuals living, working and undertaking research in these communities; and collaboration with other authors involved in this national assessment. Furthermore, this chapter explicitly incorporates the voices, expertise and knowledge of Indigenous individuals, Elders, organizations and communities, recognizing that many remote areas in Canada include Indigenous communities and First Nations, Inuit and Métis homelands. The chapter concludes with a discussion on knowledge gaps, research needs and emerging issues, and a synthesis of the state of adaptation to climate change in rural and remote communities.

This chapter presents seven key messages on the state of climate change impacts and adaptation across rural and regional communities and areas, as well as a number of short case stories from specific communities. These key messages reflect a series of priority themes that emerged from the literature review and consultations, and by drawing on the expertise of the author team. These priority themes include: enhancing adaptive capacity through knowledge-sharing, collaboration and co-creation; place-based knowledge systems; livelihoods and economy; infrastructure and transportation; health and well-being; identity, culture and society; and governance and institutions. Within these priority areas, it is important to consider how particular characteristics of rural and remote communities may support or hinder effective adaptation to climate change (*see* Box 3.2).

Box 3.2: Social factors influencing vulnerability to climate change in rural and remote communities

Vulnerability to climate change is influenced by a variety of determinants including social, cultural and political factors (e.g., access to resources, political representation and social networks), as well as individual characteristics and circumstances (Krawchenko et al., 2016). In the literature, indigeneity, gender, age and socioeconomic status are highlighted as key factors that influence individual- and community-level vulnerability to climate change impacts in Canada's rural and remote communities.

Indigeneity

First Nations, Inuit and Métis populations in Canada—especially those living in remote and/or coastal areas in the Arctic and Inuit Nunangat (Inuit Homelands)—are particularly affected by the negative social, economic and environmental impacts of climate change due to their often-close and enduring reliance on the land for sustenance, livelihoods, culture and well-being (Archer et al. 2017; Picketts et al., 2017; Government of Canada, 2016; Province of New Brunswick, 2016; Cunsolo Willox et al., 2015; Durkalec et al., 2015; Cunsolo Willox et al., 2012). It is also important to consider the ways in which current inequities experienced in Indigenous communities were created, as a result of historic and current government policies (Loring and Gerlach, 2015). At the same time, enduring connections to land and culture held by many Indigenous Peoples and communities in Canada are a source of strength, which fosters adaptive capacity.

Gendered experiences

Researchers have begun to explore the gendered dimensions of climate change in rural and remote areas, with gender being identified as a key determinant impacting individual experiences, specifically in Indigenous (Young et al., 2016; Hanrahan et al., 2014), forest-based (Reed et al., 2014), agricultural (Fletcher and Knuttila, 2016) and coastal communities (Williams et al., 2018; Women's Environment and Development Organization, 2018; Vasseur et al., 2015). In rural and remote communities, divisions of labour based on gender influence the ways in which individuals are impacted by climate change, as well as their ability to respond to these impacts. In agricultural communities in Saskatchewan, for example, environmental crises associated with climate change have been found to further entrench patriarchal gender roles that position men as "primary farmers" and women as supporters and caregivers. This positioning may lead men to be more negatively affected by the psychological impacts of climate extremes, due to their position as "primary farmers," or could make women more vulnerable due to the constant pressure to support others that are affected by climate extremes (Williams et al., 2018; Fletcher and Knuttila, 2016). In the Inuit community of Black Tickle, Labrador, men are often responsible for water retrieval. Consequently, as climate change affects water availability, single women may experience increased vulnerability to water insecurity (Hanrahan et al., 2014).

Ageing populations

Age influences the vulnerability of individuals and communities to climate change, particularly in rural and remote areas, where populations tend to be older. Specifically, many elderly people in rural, coastal communities are at higher risk due to challenges with accessing and responding to warnings related to environmental emergencies, greater reluctance to leave their homes and limited financial capabilities. These challenges are further compounded by often-limited services for older populations that are in need of both social and physical support (Krawchenko et al., 2016; Manuel et al., 2015; Rapaport et al., 2015).

Socioeconomic status

In many instances, socioeconomic factors such as high poverty rates, unemployment, food insecurity and lower levels of formal education can exacerbate and magnify climate change impacts in rural and remote communities (Loring and Gerlach, 2015; Vasseur et al., 2015; Reed et al., 2014). Residents in communities with lower average incomes are disproportionately affected by climate change impacts, in part as a result of an increasing trend in homeowner insurance costs related to property and infrastructure damage from extreme weather events (Drolet and Sampson, 2017). In addition, responses such as relocation or building protection walls to prevent or delay such damages are not affordable to all (Federation of Canadian Municipalities, 2018b; Vasseur et al., 2017). Further, options for wage earnings are limited in some rural and remote communities, and are often supplemented by activities such as hunting, fishing, trapping and gathering, which are also affected by climate change (Kornfeld, 2016; Statham et al., 2015).

3.2 Climate change is affecting rural and remote communities

Rural and remote communities often experience environmental, social, economic, cultural and health impacts from climate change disproportionately compared with urban centres. Despite these challenges, rural and remote communities display strong resilience and are often at the forefront of adaptation action in Canada.

Rural, remote and resource-dependent communities have a history of coping with socio-ecological change, which has created a culture of resilience. While uncertainty associated with climate change impacts and the speed of climate-related changes is challenging existing capacities, many communities have begun to develop and implement adaptation strategies to anticipate, prepare for and address impacts. Adaptation strategies employed by rural and remote communities across the country include gathering and sharing information related to climate change impacts and potential responses; building adaptive capacity; harnessing the use of innovative technologies; and working across jurisdictions to co-construct plans and policies that facilitate successful adaptation and ensure ongoing resilience.

3.2.1 Introduction

Canada's rural and remote communities are home to residents, businesses and organizations that typically depend on climate-sensitive natural resources and ecosystems for their culture, livelihood, transportation and well-being. At the same time, due in part to their geographic location, these communities are experiencing greater impacts from climate change than their urban, and often more southern, counterparts.

As such, rural and remote communities are often characterized as being more vulnerable to climate change than other communities in Canada (Reed et al., 2014). Many rural and remote communities, however, have in the past demonstrated high levels of adaptive capacity and resilience, including in the face of "boom and bust" cycles in market demand for natural resource products and resulting from a history of ongoing colonial legacies and other power relationships that adversely affected them. Inuit communities in Inuit Nunangat, for example, are accustomed to working within changing environments, adapting which species they hunt and when depending on availability, and relying on group memory, intergenerational knowledge-sharing, learned experiences, sharing and trade (*see* Section 3.4). Continued exposure to climate change over long periods can create "response with learning" capabilities that facilitate adaptation (Pearce et al., 2015). Adaptive capacity is challenged by uncertainty around how climate change will impact specific communities, but many have begun to develop and implement adaptation strategies, drawing on local and Indigenous Knowledge, social networks and practices of flexible resource use (Clark et al., 2016b; Young et al., 2016).

3.2.2 Knowledge-sharing and collaboration

Gathering and sharing information related to climate change impacts and potential responses is critical to adaptation efforts. Recent research highlights the importance of knowledge co-production, drawing from multiple knowledge systems and from knowledge that is experiential and place-based. For example, community-based monitoring programs and collaborative research have been used to inform decision-making on climate change adaptation. The use of local and Indigenous Knowledge has helped to support hazard avoidance, emergency preparedness, flexibility and innovation in hunting practices, as well as monitoring of pests, pathogens and weeds. Examples include the eNuk app from Nunatsiavut (eNuk, n.d.), the Northwest Territory's Knowledge Agenda (Government of Northwest Territories, 2017), and 4-H Ontario's Field Crops: Weeds, Insects, and Diseases project (4-H, n.d.). Similarly, climate change-related health monitoring has informed key adaptation strategies (*see* Table 3.4) for responding to impacts such as vectorborne and foodborne disease, reduced water quantity and quality, respiratory disease and mental health concerns.

Residents and organizations in rural and remote communities have also worked with partnering agencies at all levels of government, academia and non-government organizations to not only gather climate change-related data on risks and responses, but also communicate information related to this research (e.g., lists of safe spaces, pamphlets regarding disease outbreaks and best practices for public health related to adaptation) (Drolet and Sampson, 2017; Groulx, 2017; Pearce et al., 2012). This has included incorporating culturally relevant and locally appropriate materials into educational programming, and providing practical advice on adaptation to local homeowners, investors, businesses, governments and non-profit organizations (Groulx et al., 2014; Pearce et al., 2012).

Together, these knowledge creation and mobilization strategies have supported and enhanced adaptive capacity in rural and remote communities. For example, adaptation efforts draw from and build upon existing capacity within communities by enhancing social networks, connections to cultural practices and land-based learning, and intergenerational knowledge-sharing. Further efforts, however, are needed to reduce social barriers to adaptation (e.g., poverty, inequality, housing concerns, etc.) (Groulx, 2017). Adaptation initiatives have also contributed to building more livable and sustainable communities and local economies by incorporating a focus on local food production, alternative transportation options, age-friendly communities, clean energy practices and renewable energy project development into community planning and development efforts. Community members and concerned citizens in rural British Columbia, for example, are calling for integrated, holistic planning responses to environmental and social change (Drolet and Sampson, 2017).

Rural and remote communities are also harnessing innovative technologies in their adaptation initiatives, including the use of telehealth (i.e., the delivery of health information and services through information and communications technologies), satellite imagery to assess unpredictable conditions and social media to respond to emergencies (Taylor, 2019; Goodridge and Marciniuk, 2016). Digital reconstruction has also been used to mobilize knowledge and help to digitally preserve sites of cultural and social significance that are at risk of damage from climate change. For instance, 3D laser scanning technology was used to create a digital reconstruction of Fort Conger, Nunavut—a former settlement, military fortification and research post-dating back to 1881—an example of a polar heritage site that is at risk of destruction due to climate change (*see* Figure 3.2; Dawson and Levy, 2016; Science and Survival at Fort Conger, 2015). The digital reconstruction allows for public exploration of a site they may never see. Other technologies, such as GIS maps and 3D flood animations, have been used to better communicate climate risks related to flooding and infrastructure failure to community members (Lieske, 2015; Lieske et al., 2014).

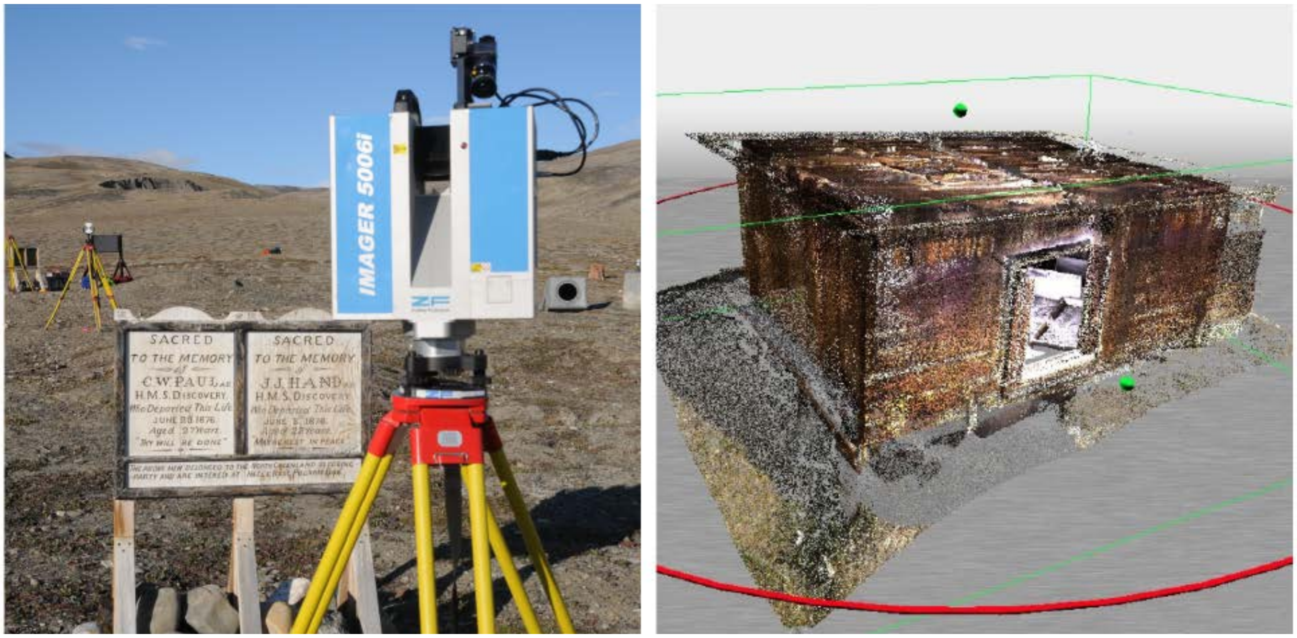

Figure 3.2: The Fort Conger historic site is being digitally preserved through the use of 3D laser scanning technology, which was used to create a digital reconstruction of the site. Source: Science and Survival at Fort Conger, 2015.

Residents of rural and remote communities have also actively participated in the development of national and provincial/territorial assessments, pilot projects, programs and policies pertaining to climate change impacts and adaptation, to ensure that their voices are heard and their circumstances are understood. Adaptation is also increasingly being supported by co-constructed planning and policy, although there is a clear and continuing need for greater local autonomy in adaptation-related decision-making, as well as for improved coordination and communication across different levels of government (*see* Section 3.8). Resilience has been enhanced in rural and remote communities through climate change action plans that are culturally relevant and that draw from social networks, experiences, diversity considerations, consensus building and place-specific emergency response plans. Specific examples of ways that rural and remote communities are leading adaptation actions across Canada are presented in Tables 3.1 to 3.6 and through various case stories included in this chapter (*see* Box 3.3).

Box 3.3: Examples of rural and remote communities across Canada leading adaptation actions

- The Bagida-Waad Alliance—a not-for-profit organization founded by the Saugeen Ojibway Nation and the Chippewas of Nawash—is documenting Indigenous Knowledge and experiences of fishers about climate change impacts on Lake Huron and in Georgian Bay, Ontario.
- Agricultural producers in rural Saskatchewan are responding to climate variability through a range of environmental management practices such as fallowing, creating windbreaks, installing farm water infrastructure and growing new crops with support from government programming and partnerships.
- Provincial officials in Nova Scotia are working with coastal planners and managers to develop strategies to reroute transportation lanes and update design standards. Also, municipal authorities in the province are using flood maps to warn future developers of projected risks, identify vulnerable key municipal infrastructure and adapt their emergency response plans and equipment accordingly.
- A number of community adaptation strategies in the Northwest Territories include educational workshops and physical activity programs to reduce health risks associated with wildfires.
- In the Nunatsiavut region of Labrador, community programs bring together youth and experienced harvesters serving as mentors to support social and cultural connections and to enhance skills, pride and food security.
- Within watershed governance structures in British Columbia, actors at multiple levels are working together to provide decision-makers and stakeholders with up-to-date information about changing water quality and flows, as well as other climate change impacts and potential responses.

3.3 Local and Indigenous Knowledge are key to adaptation and understanding climate impacts

Residents of rural and remote communities have a strong connection to the environments that they depend on for their livelihood, sustenance, well-being and way of life. Place-based knowledge systems, including local and Indigenous Knowledge, and lived experience are key to understanding and adapting to climate change impacts in rural and remote communities and areas.

Climate change impacts are dependent on a number of connected factors that are rooted in specific places. As a result, climate change is impacting individuals and communities in rural and remote areas across Canada in many different ways. It is important that place-based knowledge systems—including local and Indigenous Knowledge—be drawn upon in understanding and responding to climate change impacts. Both local knowledge and Indigenous Knowledge Systems are based on long-term, ongoing relationships between people and their natural environments. Such knowledge can provide useful insights on changing climatic conditions and on the lived experiences of those affected by climate change.

3.3.1 Introduction

In many rural and remote areas across Canada, knowledge about the environment is strongly rooted to place (Chapin et al., 2015). Place-based knowledge systems, which are critical for understanding and responding to the impacts of climate change, are a strength of rural and remote communities that is already being leveraged in many climate change governance, policy and research contexts (EPCCARR, 2018; Arnold and Fenech, 2017; Ellis and Albrecht, 2017; Government of Northwest Territories, 2017; Horning et al., 2016a, b; Cunsolo Willox et al., 2013a, b).

Indigenous Knowledge, local knowledge, and other place-based knowledge systems are commonly utilized in rural and remote Canada. Indigenous Knowledge, which is held by Indigenous Knowledge holders, has been defined as knowledge gained through cultural practices and lived experiences, including multi-generational observations, interactions with other community members, teachings and skills sharing (Pearce et al., 2015; Ford et al., 2014). Indigenous Knowledge is systematic, cumulative and continually changing as new observations and experiences occur (Pearce et al., 2015; Ford et al., 2014). At the foundation of Indigenous Knowledge Systems are generations of place-based observations and experiences; this knowledge is shared through stories, values and ways of knowing, which shape experiences, perceptions, understanding and responses to climate change (EPCCARR, 2018). Similarly, local knowledge—the knowledge that is gained from living and knowing in specific places and environments—is based on sustained interactions between people and the natural environments of which they are a part. In the context of climate change, local knowledge offers insight into human responses to changing environmental conditions (Chapin et al., 2015). Some research indicates that the rapid rate of climate change may challenge the capacity and applicability of some aspects of local and Indigenous Knowledge Systems (Pearce et al., 2015). However, due to their place-based nature, these forms of knowledge are robust, essential and have been highlighted as key to identifying and addressing the local impacts of climate change in rural and remote communities and areas (Ford et al., 2016; Chapin et al., 2015).

There are several important strengths of Indigenous and local knowledge systems in the context of understanding and responding to climate change, including: 1) understanding, monitoring and recording climate change impacts; 2) enhancing adaptive capacity and building resilience; 3) supporting sustainable risk reduction strategies; and 4) informing decision-making and policy change.

3.3.2 Monitoring and recording climate change impacts

In many rural and remote areas across Canada, place-based knowledge systems are being used to monitor the impacts of climate change (Arnold and Fenech, 2017; Savo et al., 2017; Statham et al., 2015; Gill and Lantz, 2014). For the Teetł'it Gwich'in in Fort McPherson, Northwest Territories, for example, Indigenous Knowledge is being used to monitor the environmental impacts of climate change and to provide place-based and context-specific information related to water security (Gill and Lantz, 2014). The data collected through this monitoring program has been used to create a web-based map that displays photos and videos provided by participants, ultimately producing descriptive and culturally relevant information about environmental changes (Gill and Lantz, 2014). In another example, communities throughout Nunavut used Indigenous Knowledge to provide insight into the climate changes observed in the region during the winter of 2010–2011, which included a range of climate extremes (e.g., extreme and unpredictable winds, warming temperatures), sea ice (e.g., later freeze-up, unpredictable thickness) and land conditions (e.g., icy land conditions) to inform future studies (Statham et al., 2015). In the Northwest Territories' Knowledge Agenda, the role of Indigenous and local knowledge is acknowledged as key to identifying and understanding climate change and its implications for the landscape, wildlife, traditional activities, and human health and well-being, and for informing government decision-making (Government of Northwest Territories, 2017). In Rigolet, Nunatsiavut, Labrador, Indigenous Knowledge is being used to monitor climatic changes through a community-led monitoring program, which allows community members to record environmental and health changes associated with climate change using the eNuk mobile phone application (*see* Figure 3.3; Kipp et al., 2019; Sawatzky et al., 2017). Information collected through the app is being used to promote safer travel through information-sharing, to inform policy-level decision-making and to preserve important Inuit knowledge. These examples illustrate the key role that Indigenous and local knowledge holders play in understanding the impacts and extent of climate change.

Figure 3.3: The eNuk app is a tool for ongoing and near-real-time monitoring of observations, patterns and trends in climate and environmental conditions and associated health implications. The app allows community members to record their environmental and health observations in the form of photos, videos, audio recordings and text descriptions while travelling, hunting, fishing and harvesting on the land. The app includes indicators of environmental change (e.g., thinning ice or unusual weather patterns) and elements of both physical health (e.g., unintentional injuries) and wellness (e.g., feelings and emotions associated with certain conditions or places) (eNuk, n.d.). Photos courtesy of Ashlee Cunsolo and Inez Shiwak.

3.3.3 Enhancing adaptive capacity and building resilience

Place-based knowledge systems have also been recognized as enhancing adaptive capacity and resilience to the adverse effects of climate change in rural and remote areas at both the individual and community level. For many Indigenous communities in Northern Canada, Indigenous Knowledge is based on knowledge and skills that are at the root of safe practices while out on the land (e.g., responding to environmental dangers such as changing snow, ice and weather conditions) (Ford et al., 2014). As a result, Indigenous Knowledge has contributed to the flexibility and adaptability of individuals and communities, as well as to successful hazard avoidance and emergency preparedness in the context of changing climatic conditions (Pearce et al., 2015). Place-based assessments can therefore be used not only as a way of accounting for local climatic conditions, but also as an avenue through which knowledge users can better understand adaptive capacity in specific contexts (Ford et al., 2015).

3.3.4 Supporting sustainable risk reduction strategies

The contextual nature of climate change has posed challenges for rural and remote communities in terms of creating and implementing sustainable and successful risk reduction strategies. Research examining rural and remote areas across Canada has found that incorporating place-based knowledge that is rooted in the lived experiences of local communities can positively contribute to sustainable development planning (Drolet and Sampson, 2017). For example, a study examining six rural communities in the interior and northern regions of British Columbia highlighted the ways in which each community experienced diverse climate change impacts. These communities expressed a need for adopting different approaches to sustainable development, which emphasize using a place-based approach rooted in local contexts and experiences (Drolet and Sampson, 2017). In a study examining best management practices for adapting to environmental impacts of climate change in agricultural communities in Alberta and Saskatchewan (located in the Swift Current Creek, Oldman River and Castle watersheds), community members highlighted the need to incorporate local knowledge and practices in sustainable social development planning. Agricultural producers acknowledged that, despite being subjected to changing weather stressors, they have been able to adapt by applying local knowledge from farmers, ranchers, watershed groups and irrigation districts to develop new technologies, practices and management strategies (McMartin and Merino, 2014).

3.3.5 Informing place-based decision-making and policy on adaptation

Place-based knowledge systems and the lived experiences of individuals and communities in rural and remote areas are being used to inform decision-making and policy. For example, a program examining environmental management practices for agriculture in rural Saskatchewan found that incorporating local knowledge into discussions about the uncertainties of climate change would increase the number of scenarios considered, thus helping to decrease policy concerns and ensure regional appropriateness (Hurlbert and Pittman, 2014). In areas where changes to permafrost alter existing structures, research has highlighted the role that local and Indigenous Knowledge can play in policy that relates to the built environment (Ford et al., 2015). Indigenous Knowledge Systems can also provide novel perspectives and options for action, which extend beyond scientific knowledge and help highlight priorities, build understanding and advance climate change adaptation (EPCCARR, 2018).

Despite the important knowledge highlighted in this chapter, there is a dearth of information focused on the place-based implications of climate change for those living in rural and remote communities in Canada (Rapaport et al., 2015). Although changes to the environment are affecting local peoples' relationships with and knowledge about the land (Durkalec et al., 2015; Harper et al., 2015, 2012; Cunsolo Willox et al., 2012), it is vital to continue supporting and drawing from Indigenous and local knowledge to effectively understand and respond to the context-specific nature of climate change impacts in rural and remote communities and areas (*see* Case Story 3.1).

Case Story 3.1: The Saugeen Ojibway Nation and tracking of climate change impacts on whitefish

Many families in the Saugeen Ojibway Nation and Chippewas of Nawash rely closely on whitefish populations in Lake Huron and Georgian Bay for their culture, sustenance and livelihoods. As wind speeds increase and temperatures rise due to climate change, fishers have begun to notice changes to the fish in these areas. The Bagida-Waad Alliance was founded by these fishing communities to serve as a local research organization, with the aim of establishing a baseline for fish populations, tracking climate change impacts on Lake Huron and Georgian Bay and documenting Indigenous Knowledge of fishers. Leveraging the stories and experiences of fishers and Elders is expected to help the community develop its climate change adaptation capacity, as well as preserve place-based knowledge systems for future generations (Johnson, 2019).

3.4 Climate change is challenging livelihoods and economies

Climate change is already impacting many of the economic sectors and subsistence activities that rural and remote communities rely on for their livelihoods and economic well-being. Local adaptation strategies are helping to protect traditional economies through planning and capacity building, changing land practices and use of technology.

Changing sea ice and ocean conditions, warmer temperatures and drought are already impacting economic sectors such as agriculture, forestry, fishing and tourism, as well as subsistence activities such as hunting and gathering. These industries and related activities are often dependent on climate-sensitive natural resources and are vital to livelihoods and economic well-being in rural and remote communities. Despite the significant intersecting challenges, individuals and organizations in many rural and remote communities have taken important steps to protect and adapt their livelihoods, while also encouraging new development options such as alternative energy projects. Many residents that rely on land-based subsistence economic activities have also adopted coping and adaptation strategies, which include changing travel times and routes, shifting to other target species, using new digital technologies and drawing on strong social networks to share food, equipment and knowledge. These strategies often come at a financial and personal cost, however, and require support and care to avoid maladaptation (i.e., adaptation actions that inadvertently increase the risk of adverse outcomes).

3.4.1 Introduction

Many rural and remote communities in Canada have mixed economies with both formal (cash or wage-based) and informal (primarily non-cash) sectors playing important roles. Further, many rural and remote communities depend on natural resource industries—including agriculture, forestry, fisheries, energy and mining—for their economic base and to support livelihoods (*see* Figure 3.4; Drolet and Sampson, 2017). In turn, these communities and their residents make vital contributions to provincial and national economies (Dampier et al., 2016). In more than 1,800 rural and remote communities in Canada—the majority with populations of 10,000 or less—an average of 30% of the local labour force is dependent on natural resource sectors for employment (*see* Figures 3.5 and 3.6). Current and potential climate change impacts on natural resource sectors, particularly those that have yet to develop or implement adaptation strategies, therefore make many rural and remote communities economically vulnerable.

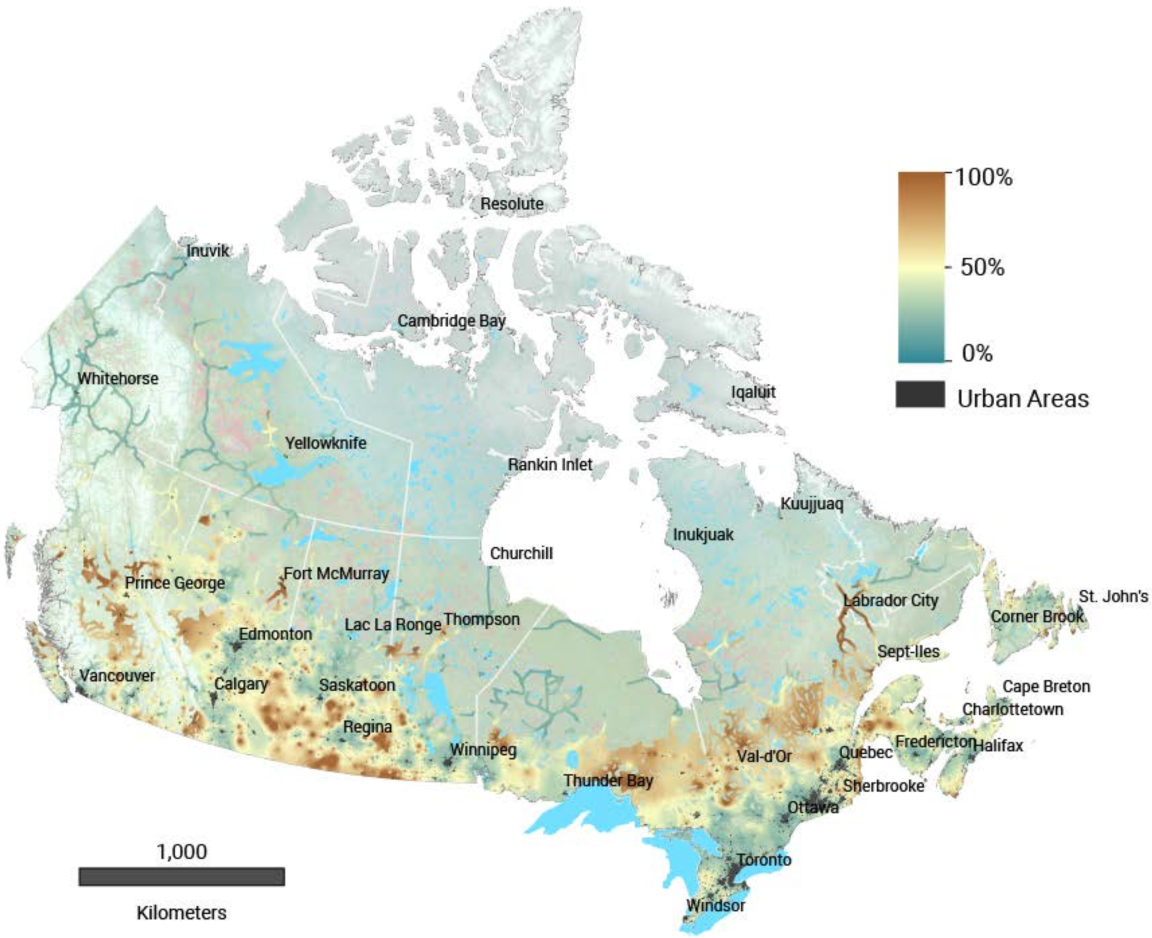

Figure 3.4: Map displaying the average labour-force dependency of communities across Canada on natural resource sectors—including agriculture, fisheries, forestry, energy and mining—for the period 2001–2016. The colours on the map range from blue to red, where blue signifies low dependency, mostly in and surrounding large urban areas, and red indicates high dependency, which is mostly in rural and remote areas. The map shows that natural resource sectors provide as much as 50–100% of the base economic sector income for many rural and remote communities across Canada. Base economic sectors include natural resources (fisheries, agriculture, forestry, minerals, and petroleum and coal), utilities and construction, and manufacturing. Source: Eddy et al., 2020a, b.

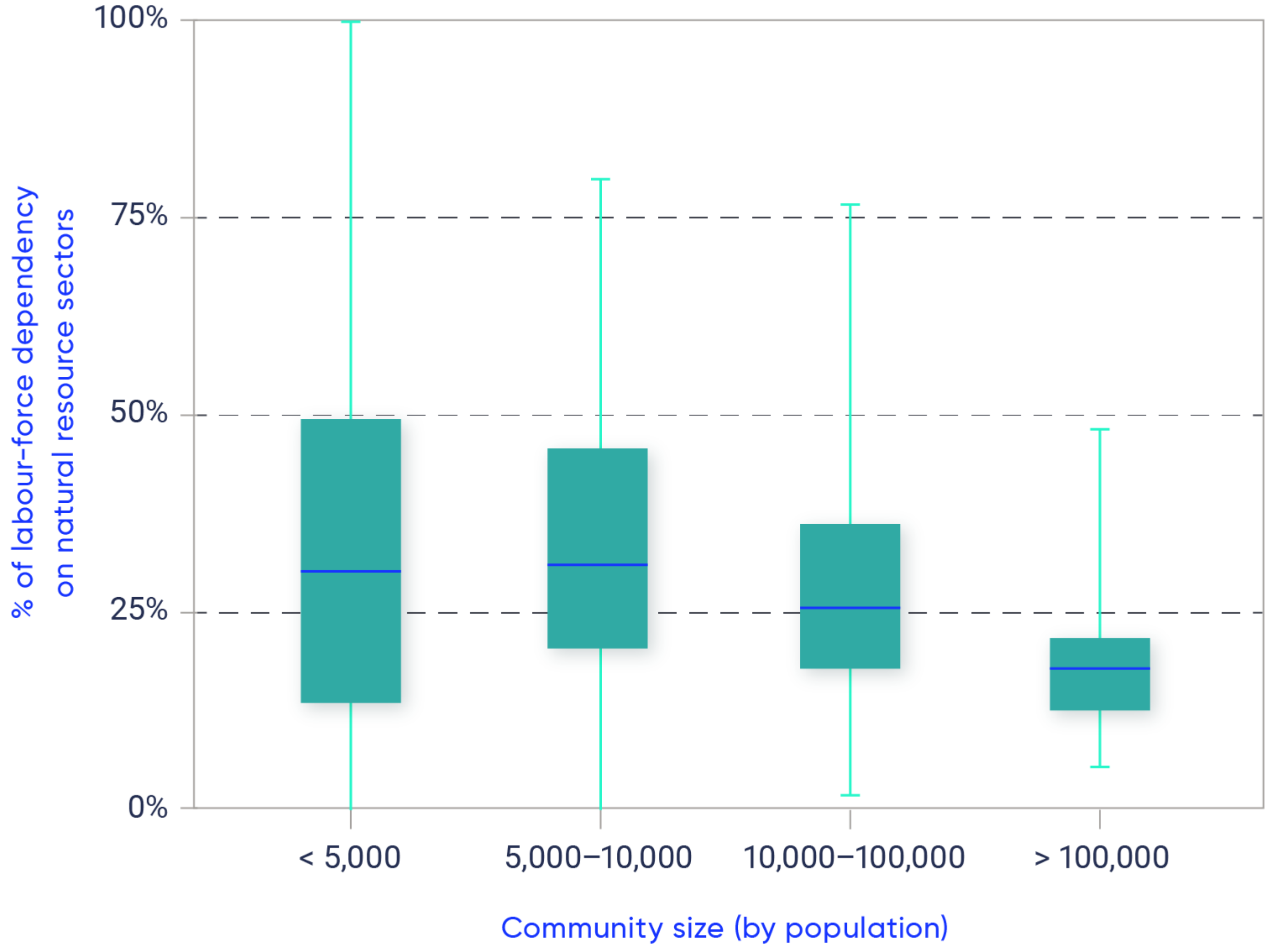

Figure 3.5: Graph illustrating the average labour-force dependency of different-size communities in Canada on natural resource sectors, as a percent of base economic sector income, for the period 2001–2016. Base economic sectors include natural resources (fisheries, agriculture, forestry, minerals, and petroleum and coal), utilities and construction, and manufacturing. Communities are grouped according to four different population sizes: 1) less than 5,000; 2) 5,000–10,000; 3) 10,000–100,000; and 4) greater than 100,000. The boxes indicate the maximum and minimum values for 95% of the data, the solid line within each box indicates the average value and the vertical lines extending from the boxes indicate the full data range. The graph shows that the labour force in communities with smaller populations tends to be more dependent on natural resource sectors than in communities with larger populations. Source: Eddy et al., 2020a, b.

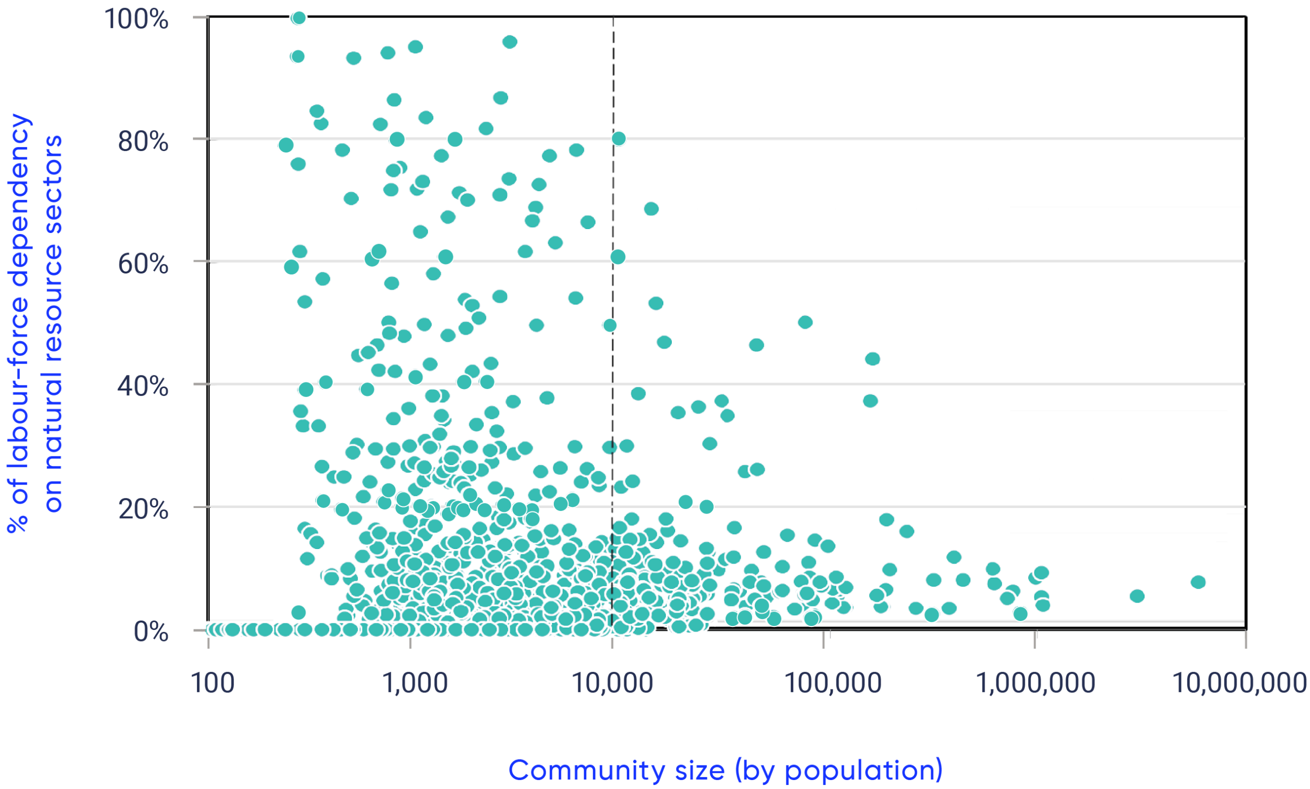

Figure 3.6: Graph showing the distribution of the average labour-force dependency on natural resource sectors, for the period 2001–2016, for communities in Canada with populations ranging from 100 to 10,000,000 people. Labour force dependency is defined as the percentage of labour force income derived from natural resources as a proportion of the total base sector income. Base economic sectors include natural resources (fisheries, agriculture, forestry, minerals, and petroleum and coal), utilities and construction and manufacturing. Each dot in the graph represents a different community in Canada. The vertical dotted line illustrates the population threshold used in this chapter for communities that are considered as being rural and/or remote (e.g., communities with a population of 10,000 or less). The graph shows that the labour force in communities with smaller populations tends to be more dependent on natural resource sectors than in communities with larger populations. Source: Eddy et al., 2020a, b.

Climate change impacts on informal economies such as hunting, fishing, trapping and gathering threaten livelihoods and food security. Residents often rely on these culturally significant activities to supplement wage-income sources in locations where wage-sector employment prospects may be limited (Kornfeld, 2016). Further, when access to locally harvested food (e.g., "country food") is restricted, residents are often forced to switch to costly, nutritionally inferior store-bought products (Statham et al., 2015). Many of these communities are within the traditional territories of First Nations, Inuit and Métis populations whose livelihoods, culture and well-being are deeply connected to the health of the land and water (Gill and Lantz, 2014; Cunsolo Willox et al., 2012). This makes these populations more vulnerable to climate change than populations in urban environments (Kornfeld, 2016). These same rural and remote communities are often experiencing some of the most severe and cumulative effects of climate change. Dependency on ecosystem resources means that climate change impacts on the economies and livelihoods of rural and remote communities in Canada are particularly acute.

3.4.2 Vulnerability and adaptation in the natural resource sectors

Climate change is expected to increase the vulnerability of natural resource-dependent economies due to impacts on supply, demand, and harvesting and processing operations. For example, climate variables (e.g., temperature and precipitation) and weather-related stressors play important roles in growing season length, as well as agricultural activities and productivity, making the agriculture sector highly vulnerable to climate change (Akkari and Bryant, 2016). Temperature extremes and extreme events have affected growing conditions across the country. Although hotter, drier summers and extreme weather events—including drought, heat waves and flooding—have negatively impacted many agricultural areas, prolonged growing seasons and increasing frost-free days could also provide new opportunities (Roussin et al., 2015; McMartin and Merino, 2014). Efforts to increase local food production as a result may enhance food security, create new jobs and income, and reduce reliance on food imports, which has the added co-benefit of reducing greenhouse gas (GHG) emissions related to the transportation of imports and reduced vulnerability to transportation system disruptions (Roussin et al., 2015). Research highlights the need to ensure that agriculture in new areas does not amplify or exacerbate existing risks. For example, caution would be needed in areas where there are existing water shortages and high demand on water for crop irrigation, as is the case in the area near the Oldman Dam in Alberta (Yusa et al., 2015).

The forest industry and forest-based communities are being affected by multiple impacts related to climate change. The mountain pine beetle epidemic, for example, has provided a powerful illustration of related threats (e.g., loss of merchantable timber and related jobs and business revenues) and opportunities (e.g., for economic transition and biomass energy production) (Drolet and Sampson, 2017; Furness and Nelson, 2016; Blanco et al., 2015). Climate change is also affecting the availability of commercially harvested fish species and impacting fishing seasons and locations. For instance, increases in warmer water species like silver hake in Newfoundland and Labrador, and American lobster across the Scotian Shelf have been observed (Bernier et al., 2018). Also, herring seasons are being extended and there is a need to travel farther offshore for shrimp due to warmer near-shore waters in the Acadian Peninsula (Vasseur et al., 2017). In the Pacific Ocean, fisheries stocks are being affected by warming, acidification and extreme events such as marine heat waves. For example, increasing ocean temperatures are believed to have negatively impacted the survival, size and condition of Chinook Salmon, reducing catch sizes and value (Holsman et al., 2019).

Climate change is also impacting tourism potential in rural and remote areas, many of which are increasingly relying on tourism as a component of their local economies. For example, warmer temperatures, changing sea ice dynamics and shifting weather patterns are expanding existing opportunities as well as opening up new ones in some areas (*see* Sector Impacts and Adaptation chapter). Increased tourism, however, also brings associated direct and indirect impacts that negatively affect ecosystems and transportation, such as increased air travel, greywater discharge and GHG emissions (World Wildlife Fund, 2019; Stoddart and Sodero, 2015). Not all rural and remote communities are benefitting from expanded or new tourism opportunities due to climate change (*see* Table 3.1). For example, many ski areas are negatively impacted by changing weather patterns, shorter winter seasons and precipitation changes, and are becoming more reliant on snow-making equipment, which increases costs and water demand (Hock et al., 2019; Gilaberte-Búrdalo et al., 2014). Other impacts—including thawing permafrost, rising sea levels, storm surges, flooding and erosion—are leading to the loss and destruction of valued artifacts and heritage sites, such as Fort Conger, Nunavut (*see* Section 3.2). This is not only leading to the loss of cultural heritage, but is also damaging potential tourism opportunities (Abram et al., 2019; Meredith et al., 2019; Dawson and Levy, 2016). Other examples of impacts and adaptation efforts within each of these natural resource sectors are provided in Table 3.1 (*see* Sector Impacts and Adaptation chapter).

Table 3.1: Climate change impacts and adaptation measures in rural and remote sectors

SECTOR	CLIMATE CHANGE IMPACTS	ADAPTATION MEASURES
Agriculture and livestock	• New agricultural opportunities in West Kootenays, BC due to an extended growing season for vegetable crops include the possible expansion of fruit and vegetable varieties; use of poorer quality lands for niche crops such as tree fruits and grapes; and potential to increase mixed small-scale agriculture (Roussin et al., 2015). • Scarce water resources are further depleted due to expanded agricultural development in newly cultivated land (Yusa et al., 2015). • Use climate data and projections from climate models in combination with soil information to assess the agricultural potential of a region and plan for a change in the range and types of crops grown (Roussin et al., 2015). • Heat waves are increasing risks of dairy cow mortality in southern Ontario (Bishop-Williams et al., 2016).	• Farm-level adaptation includes four main and often interdependent approaches: technological development; government programs and insurance; farm practices; and farm financial management (Akkari and Bryant, 2016). • Use climate and crop insurance data to assess costs and risks and support farm planning (Akkari and Bryant, 2016). • Shifts in cropping regimes and seeding times (McMartin and Merino, 2014). • Precision agriculture and other types of water reduction methods are used to conserve water, while maintaining harvest yields (Nicol and Nicol, 2018). • Use climate data and projections from climate models in combination with soil information to assess the agricultural potential of a region and plan for a change in the range and types of crops grown (Roussin et al., 2015).

SECTOR	CLIMATE CHANGE IMPACTS	ADAPTATION MEASURES
Agriculture and livestock (continued)	• In the Province of Quebec, yield declines are expected for wheat, soybeans, green peas, onions, tomatoes and cabbage (with potential implications for costs of dairy production); however, yields for corn, sorghum, canola, sunflowers, potatoes, tobacco and sugar beets may increase (Akkari and Bryant, 2016). • Continued northward expansion of areas feasible for small cereal crops are expected, particularly in north-central Canada, while summer water deficits in some boreal regions will accelerate soil carbon losses and diminish already limited soil quality (King et al., 2018).	• More proactive water management (McMartin and Merino, 2014). • Use of farm environmental management practices and water infrastructure to reduce vulnerability (Hurlbert and Pittman, 2014). • Monitor herds more frequently during heat waves, using heat abatement strategies such as fans and soaking, communicating heat wave warnings through various media channels (Bishop-Williams et al., 2016). • Implement nutritional changes and improved breeding techniques (Rojas-Downing et al., 2017; Climate Action Initiative, 2013). • Combine winter water storage to feed summer irrigation and develop drought-adapted crop varieties to support production and expansion (King et al., 2018).
Forestry	• More frequent and severe droughts, increased windstorms and changes to growing seasons together with other changes have reduced harvest revenues and increased fluctuations in timber supply (Furness and Nelson, 2016). • Increased forest fire frequency, area burned and fire seasons (Blanco et al., 2015).	• Use of guidebooks to assess adaptive capacity and measures to strengthen community assets (e.g., Reed et al., 2014; Pearce and Callihoo, 2011). • Thin and prune forests to reduce fire and drought risk (Furness and Nelson, 2016). • Improve forest health monitoring and response to disturbances (e.g., salvage logging and treatments) (Furness and Nelson, 2016).

SECTOR	CLIMATE CHANGE IMPACTS	ADAPTATION MEASURES
Forestry (continued)	• Increased forest pest and disease infestations (e.g., warmer winter conditions led to a mountain pine beetle epidemic that has destroyed over 18 million acres of forest in British Columbia since the 1990s, with the beetle's range expected to continue expanding into Canada's northern and eastern pine forests) (Natural Resources Canada, 2018b). • Market and policy pressures, due to the awareness of climate change impacts, for energy sources that reduce GHG emissions lead to the use of woody biomass in bioenergy projects (Blanco et al., 2015).	• Climate-informed modelling of future timber supply (Furness and Nelson, 2016). • Adjust planting strategies for a diversity of species, trial seed from a variety of provenances and keep a mix of age classes to spread risk (Furness and Nelson, 2016). • Research expected impacts and changes that could be made; adjust work programs, processes, practices or structures to reduce vulnerability (Furness and Nelson, 2016). • Generate woody biomass from reductions in stand density to reduce risk of future wildfires, which can support local bioenergy projects and reduce GHG emissions (Blanco et al., 2015).
Fisheries	• The herring fishery is extended; shrimp are further offshore due to warmer near-shore waters; lobsters are larger due to milder winters; and there is increased prey in the Acadian Peninsula, New Brunswick (Vasseur et al., 2017). • Collecting shellfish is more difficult in areas that are experiencing sea-level rise (Vasseur et al., 2017).	• Fishers in New Brunswick are working with government scientists to report new species and predict biodiversity changes; assess infrastructure risks; and improve key fisheries infrastructure to enhance resilience to storm events (*see* Atlantic Provinces chapter). • Reduced quotas and regional fisheries closures are used to manage and support declining fish stocks (Dawson, 2019).

SECTOR	CLIMATE CHANGE IMPACTS	ADAPTATION MEASURES
Fisheries (continued)	• Damages to fishing-related infrastructure is particularly challenging for communities with limited ability to afford expensive coastal defenses or relocation (Vasseur et al., 2017). • Pacific salmon fisheries are being impacted by a rise in ocean temperature (Holsman et al., 2019).	
Tourism	• Reduced sea ice duration and extent in Arctic Canada (Pizzolato et al., 2014). • Increased tourism potential and the associated economic benefits and growth in cultural awareness (Johnston et al., 2017). • Increased cruise ship traffic in the Arctic can lead to localised warming (Messner, 2020). • Greywater discharge impacting fragile Arctic ecosystems (World Wildlife Fund, 2019). • Decreased snowpack and unpredictable weather events (Bleau et al., 2015). • Reduced length of winter sports seasons (Rutty et al., 2017). • High water usage with increased snow-making at ski resorts (Gerbaux et al., 2020). • Lower numbers of visitors to ski resorts as a result of deteriorating conditions for snow-based activities (Rutty et al., 2017).	• Services and opportunities for tourists developed by locals living in Arctic regions. • A focus on four-season tourist opportunities, rather than season-specific tourism activities. • Increased communication with tourists to inform them of potential weather events (Bleau et al., 2015). • Smaller resorts are purchased by larger companies that are more able to adapt to climate change (Sorensen, 2016). • Greater reliance on snow-making (Rutty et al., 2017). • A focus on four-season opportunities and activities to reduce the dependence on season-specific activities (Rutty et al., 2017).

3.4.3 Adaptation responses and opportunities

Residents of rural and remote communities have adopted numerous adaptation strategies to address climate change impacts (*see* Case Story 3.2), including in response to changes in subsistence economies. For example, adaptation related to hunting and food security include changing travel routes on the land for hunting; altering hunting patterns by learning to hunt new species as others change when ecosystems shift; increasing preparation and supplies for hunting trips; using new digital technologies for increased safety; and drawing on strong social networks to share food, equipment and knowledge (*see* Table 3.2). In Nunavut, for example, there have been reductions in caribou availability and quality (e.g., caribou are described as being skinnier, with less fat), along with shifts in migration to areas requiring further travel and with greater access restrictions. Under such conditions, hunters in Ulukhaktok, Inuvialuit Settlement Region, shifted their focus from harvesting caribou to muskox. Declining muskox populations now face increased harvest pressure, and hunters must travel further to hunt with varying success, leading to greater stress on the herds and on people who rely on muskox for food security (Fawcett et al., 2017). Longer, land-based routes are often harder on equipment and require more planning and supplies (Durkalec et al., 2015). Further, measures such as replacing canvas tents with cabin structures that can store supplies and withstand stronger winds—or replacing and purchasing new, often expensive safety equipment—are not feasible for all (Archer et al., 2017). In addition, meat returns may be reduced despite higher costs. Low-income hunters, including unemployed individuals and retirees that are dependent on pensions, are at particular risk from such challenges (Statham et al., 2015). New safety risks have also been introduced, especially for inexperienced hunters, as a result of shifting to unfamiliar routes, a reliance on technologies that can and do fail, and snowmobiles breaking down and being expensive to fix (Clark et al., 2016a, b). Reciprocity is also important in social networks: those less able to harvest country food (often due in part to climate-related changes) may become less likely to receive community and/or family support over time. Nevertheless, many communities continue to depend on sharing networks to support subsistence economies in a changing climate. With fewer people hunting, many hunters have increased the numbers of community members for which they provide, although this may be increasingly challenging with declining harvests and further climatic and environmental stressors (Statham et al., 2015).

Table 3.2: Examples of existing and future adaptation strategies to address climate change impacts on informal economies in rural and remote communities across Canada

EXISTING ADAPTATION STRATEGIES	REFERENCES
Added caution and emergency preparedness, such that land users are prepared to overnight and make a shelter, call for help if needed, seek additional guidance from elders before leaving, consult satellite imagery of sea ice and weather forecasts, pack more supplies (e.g., gas, food and cooking fuel, tent, parts, extra clothing and ammunition), and stock gas barrels on land during the winter months for overland travel.	Clark et al., 2016a, b; Pearce et al., 2015; Statham et al., 2015
Altered trail routes and/or hunting locations and related modes of travel (e.g., abandoned boats and travel overland by ATV).	Clark et al., 2016a, b; Pearce et al., 2015; Statham et al., 2015
Use of new technology to address changing, unpredictable conditions combined with traditional navigation skills and knowledge (e.g., satellite navigation systems and emergency satellite response devices, CB and Very High Frequency radios, satellite phones, and distress beacons); widespread use of the internet (e.g., social media to share food and equipment, check online weather forecasts and sea ice reports, request help, coordinate unofficial search and rescue trips, satellite navigation relay); stronger (e.g., aluminum) boats and structures (e.g., cabins vs. tents equipped with stoves, fuel and basic provisions at strategic locations).	Archer et al., 2017; Fawcett et al., 2017; Clark et al., 2016a, b; Pearce et al., 2015
Adapting species hunted according to what is available (e.g., from caribou to muskox, from seals to caribou during longer boating seasons, and from marine-based to land-based animals during the dangerous sea ice season).	Clark et al., 2016a, b; Pearce et al., 2015; Statham et al., 2015
Experienced hunters often make adaptive decisions (e.g., changing trail routes) and then share these with the community through social networks.	Clark et al., 2016a, b
Education and capacity building that strengthens land-based learning and intergenerational knowledge-sharing (e.g., traditional skills workshops, prevention programs, young hunter programs).	Clark et al., 2016a, b
Selling country food to offset increased expenditures on hunting equipment and safety technology, facilitated by markets and social media groups.	Statham et al., 2015

EXISTING ADAPTATION STRATEGIES	REFERENCES
Household food strategies such as switching to cheaper and less preferred foods, reducing food intake, eating elsewhere (e.g., at a friend's or family member's house) and selling belongings.	Statham et al., 2015
Community sharing, intercommunity trade and fostering social capital (e.g., sharing of food, equipment, knowledge).	Clark et al., 2016a, b; Statham et al., 2015
Community-based food programs.	Statham et al., 2015

FUTURE ADAPTATION STRATEGIES	REFERENCES
Ongoing, community-based environmental monitoring, recording of systematic observations of environmental conditions that draw from Indigenous Knowledge and local ways of understanding and interacting with the environment.	Government of Canada, 2016; Gill and Lantz, 2014;
Community climate change adaptation plans that are directly linked to specific places on the landscape and ongoing place-specific monitoring.	Gill and Lantz, 2014
Enhanced harvester assistance programs and support for the generation and transmission of skills among younger Inuit to travel and hunt under changing conditions.	Clark et al., 2016a, b
Improved financial awareness and budgeting skills to assist in coping with food-related stresses.	Statham et al., 2015

Growing demand for more sustainable, less carbon-intensive products and climate-related policy changes (e.g., carbon credits) challenges existing ways of operating in natural resource sectors. This creates new opportunities and encourages alternative development options that aid in transitioning to a more sustainable local economy (Drolet and Sampson, 2017). Examples include those noted above in agriculture, forestry, fisheries and tourism, as well as new biomass, wind and solar energy projects (Dampier et al., 2016; Kornfeld, 2016; Schroth et al., 2015). Hybrid renewable energy projects have been successfully implemented in Deer Lake and Fort Severn, Ontario, and in Colville Lake, Northwest Territories (Arriaga et al., 2017). These efforts have been successful in reducing reliance on fossil fuels and associated spills, transport costs and GHG emissions. While there are some concerns about maladaptation—including potential negative ecosystem impacts, biomass supply and accessibility, transportation costs and, in particular, air quality from biomass energy production—these negative outcomes can be offset by the potential benefits of sustainable energy systems (Blanco et al., 2015). Skills training and local investments in new technology, innovation and transition planning may be required to support economic transition (Drolet and Sampson, 2017). Attention to "just transitions"—which require collaboration, respect, worker support and shared financial costs to build a sustainable future for communities—is essential for moving forward (Government of Canada, 2018). Government-imposed requirements for corporate carbon footprint reductions and green investment treaties with commitments to reduce GHGs, for example, have the potential to support such transitions (Kornfeld, 2016). Lifecycle analyses and assessment of payback periods for initiatives seeking resiliency to climate change and extremes have also been identified as helpful strategies (McMartin and Merino, 2014).

In summary, the traditional industries and related jobs that rural and remote communities rely on face significant threats that are linked to circumstances including, and exacerbated by, a changing climate and environment. These communities are facing challenges associated with extreme weather events, rising sea levels, retreating sea ice, declining traditional food sources and changes in the populations of target species for resource sectors. To overcome these challenges, communities have taken important and often proactive measures to protect and adapt the subsistence harvesting and natural resource-based industries that support their livelihoods. These adaptations, however, continue to come at a cost and draw on human, social and financial capital. There is a need for ongoing attention to the threat of maladaptation, such as overharvesting of species or new agricultural activities that add excess stress to local water, forest and soil resources. Further support for adaptation can come from knowledge and technology sharing to better predict impacts and changes, investment in resiliency measures, and provision of technical expertise and training for rural and remote communities to provide new skills and knowledge relevant for a changing environment. In the longer term, there may be a need to support more significant measures in some circumstances, like managed retreat (i.e., the purposeful and coordinated movement of people and buildings away from risks) due to sea level rise or the development of new food and water resources.

Case Story 3.2: Government programming and partnerships in support of farm-level adaptation in Saskatchewan

Agricultural producers are playing a leading role in innovating responses to climate variability. They are implementing environmental management practices (such as fallowing, creating wind breaks and installing farm water infrastructure) and other measures (such as direct seeding and growing new crops like canola and lentils) that reduce farm- and ranch-level vulnerability to climate change impacts, including revenue loss due to drought (Hurlbert and Pittman, 2014).

Some of these innovations have been supported by government programs, such as the Canada-Saskatchewan Farm Stewardship Program (FSP) (FSP, n.d.) and the Farm and Ranch Water Infrastructure Program (FRWIP) (FRWIP, n.d.). Each of these programs has assisted thousands of projects or producers in Saskatchewan each year with on-farm projects. The FRWIP helps to address drought by financing infrastructure projects such as dugouts, wells and water pipelines that increase water access. Federal and provincial governments share the costs with the beneficiary (e.g., farmer, rancher or municipality). The FSP supports environmental farm plans and beneficial management practices that assist with climate change adaptation or that maintain or improve water resources and biodiversity (e.g., through reduced soil erosion and improved pasture management).

After a multi-year drought in 2008, producers pushed for the decentralization of program administration from federal to provincial governments. The federal government continued to provide technological and engineering expertise, and the non-profit Provincial Council of Agriculture Development and Diversification Boards for Saskatchewan Inc. (PCAB) worked with producers to identify beneficial management practices and served as a networking organization to foster interactions between governance institutions at multiple levels, including local farms and grassroots organizations. This shift was identified as more effective in terms of localized adaptation, but also requires grassroots leadership.

One challenge, particularly within rural municipalities without a sufficient tax base to invest in infrastructure projects, has been the requirement for stakeholders to provide matching funds. Inconsistent and uncertain funding has also discouraged some stakeholders from taking advantage of the programs, and thus from implementing adaptation measures. Other challenges include limited staff resources within responsible agencies and political inertia.

3.5 Critical infrastructure and services are at risk

Critical infrastructure and related services, particularly in rural and remote coastal communities, are at risk of failure and disruption from increases in the number and severity of extreme weather events. In response, a growing number of these communities are mainstreaming climate change considerations into community planning and design, and are beginning to reimagine, reinforce and rebuild their built environments.

Rural and remote communities and areas in Canada often struggle with stressed and degraded infrastructure, a retreat from service programming and the centralization of resources and services. Increases in the frequency and intensity of extreme weather events, flooding, sea level rise, permafrost thaw, wildfires and other climate-related changes are substantially exacerbating these challenges. As a result, transportation and energy networks, delivery of services, and infrastructure that support activities necessary for daily life continue to face greater risk of failure and disruption. In response to increasingly severe and unpredictable climatic conditions, rural and remote communities are developing innovative adaptation strategies to address local and regional challenges. These include the consideration of climate change, natural infrastructure and the need for sustainable, livable communities in infrastructure and community planning. Projects that reduce reliance on vulnerable, fossil fuel-dependent energy and transportation networks are important to consider in the development of adaptation strategies. Information technology is also being used to better communicate risks of climate-related infrastructure failure and service disruptions, and to document vulnerable—and in some cases lost—heritage resources.

3.5.1 Introduction

Across Canada, adequate access to infrastructure and services is a growing concern for many rural and remote communities that are experiencing stressed and degraded infrastructure, and a retreat from service delivery. Changing environmental conditions are posing further challenges for both critical and community infrastructure in rural areas (*see* Box 3.4; Berner et al., 2016). Extreme weather events (e.g., high winds, increased precipitation, drought, ice storms, heat waves and storm surges), inland and coastal flooding, sea level rise, permafrost thaw and forest fires are having a significant impact on the built environment in these settings. Regionalization and reduction of services in rural communities forces residents to travel longer distances for services such as medical care and, therefore, to become increasingly reliant on vulnerable transportation networks (e.g., poor, seasonal or non-existent roads, and lack of alternative transportation options). Those responding to emergencies are also at increased risk due to vulnerable rural infrastructure (Nova Scotia Department of Environment and Climate Change, 2018). This makes the consideration of climate change impacts in planning, zoning and land-use decisions vital in reducing risk from climate impacts that adversely affect rural and remote communities (Doberstein et al., 2019).

Box 3.4: Critical and community infrastructure

According to Public Safety Canada, critical infrastructure is “essential to the health, safety, security or economic well-being of Canadians, and the effective functioning of government.” Disruptions “could result in catastrophic loss of life, adverse economic effects and significant harm to public confidence.” The agency identifies ten sectors of critical infrastructure, including health, information and communication technology, and transportation (Government of Canada, 2020). Examples of community infrastructure include municipal buildings, recreational facilities, schools and grocery stores (Government of Northwest Territories, 2017). Facilities such as recreation or school buildings often have multiple uses and contribute greatly to community functioning and well-being. For example, in Tofino, British Columbia, the community centre has been built with emergency preparedness in mind, containing a generator and supplies to serve people displaced by any emergency event, as well as for hosting regular events, classes and exercise opportunities (Studio 531, 2019). The loss of, or damage to, these facilities can be devastating (Lebel, 2014).

3.5.2 Transportation and energy systems

Transportation infrastructure—including roads, bridges, railways, airstrips, marine shipping routes and trails—are commonly reported in the literature and by community stakeholders as being the most critically the type of infrastructure most dramatically affected by climate change. These impacts are especially pronounced for ice roads. Evidence suggests the length of time that ice roads are viable has already been significantly reduced; in the future, rising temperatures and increased precipitation may be enough to limit the formation of ice roads of sufficient thickness for the transportation of essential goods and materials in many of the areas that now rely on them (Mullan et al., 2017). Recent projections suggest that damage to infrastructure from climate-related flooding, erosion and permafrost melt is likely to result in the greatest financial costs to communities, and that infrastructure such as roads, bridges, water management facilities and revetment systems are likely to require the most investments (Federation of Canadian Municipalities and Insurance Bureau of Canada, 2019; Federation of Canadian Municipalities, 2018a). Recent research suggests that, among the top priorities for adaptation in rural and remote communities, is the need to address climate change impacts to infrastructure that result in interruptions to residents' daily activities, such as shopping, visiting family and receiving medical treatment (Manuel et al., 2015).

Energy grids and systems are another commonly cited category of rural infrastructure that is negatively affected by climate change, mainly due to failing transmission lines, the high cost of fuel and transportation, and climate-vulnerable transportation routes. Many remote communities across Canada rely solely on diesel power and a grid connection is often not a viable or reliable option; as such, alternatives must be explored, such as natural gas generators and locally generated renewable energy sources (wind energy, solar energy and biomass heating) (Natural Resources Canada, 2018a; Knowles, 2016). Climate change awareness, policies and programs have encouraged the development of new renewable energy projects and other infrastructure aimed at reducing reliance on fossil fuels (Government of Canada, 2017; Province of New Brunswick, 2016).

3.5.3 Regional variation in climate change impacts to infrastructure

While rural and remote communities across Canada are experiencing changing and variable climatic conditions, those located in the northern parts of the country are seeing more pronounced impacts to infrastructure due to rapidly increasing temperatures; changing precipitation patterns; increases in extreme and warm weather events; continued melting of Arctic sea ice, glaciers, and ice caps; rising sea levels; thawing permafrost; and coastal erosion (Bush and Lemmen, 2019; IPCC, 2018). These conditions are already evident and are having serious impacts on infrastructure in northern communities (Berner et al., 2016; Dawson and Levy, 2016; Ford et al., 2015; Boyle et al., 2013).

In more southern regions, rural communities are also concerned about more extreme weather events that cause immediate impacts such as flooding, ice storms and heat waves, and that have the potential to cause damage to critical infrastructure (Félio, 2017; Caldwell, 2015). Rural coastal communities have the added threats of flooding, sea level rise and coastal erosion impacting their infrastructure and lives (Arnold and Fenech, 2017; Vasseur et al., 2017; Manuel et al., 2015; Webster et al., 2014). For example, buildings and services that are instrumental to daily life—such as housing, healthcare facilities, community centres, post offices, grocery stores, and water and wastewater treatment—are increasingly at risk of failure, particularly from flooding and extreme weather events (Félio, 2017). In Atlantic Canada, for example, disruption to these services and access to crucial community infrastructure due to changing climatic conditions is increasing the vulnerability of ageing communities (Krawchenko et al., 2016; Manuel et al., 2015). Rural and remote communities that have one or only a few roads into and out of their communities—found in both coastal and remote regions—are particularly vulnerable to climate change, due to potential isolation when roads are washed out, which can affect the availability of food and services (Mullan et al., 2017; Krawchenko et al., 2016; Vodden et al., 2012).

3.5.4 Adaptation responses and opportunities

Rural and remote communities have undertaken a number of different approaches to infrastructure adaptation, which are often tailor-made to their specific needs and contexts (*see* Table 3.3; Case Story 3.3). These include assessing the vulnerability of current municipal infrastructure; incorporating climate change into community planning, primarily by updating codes, practices and designs; and constructing new infrastructure with a longer service life (Government of Canada, 2017; Government of Northwest Territories, 2017; Indigenous and Northern Affairs Canada, 2017). Other responses include altering emergency transportation routes, diversifying energy sources, developing local action plans to transition to low carbon economies, and planning for smart growth and sustainable, livable communities. These include communities that facilitate healthy ageing, reduce reliance on daily commuting, and recognize the use of natural infrastructure (such as forests and wetlands) to reduce climate change impacts (Government of Canada, 2017, 2016; Government of Ontario, 2016; Krawchenko et al., 2016; Province of New Brunswick, 2016; Manuel et al., 2015).

Table 3.3: Infrastructure-related adaptation responses in rural and remote communities across Canada

CATEGORIES OF ADAPTATION RESPONSES*	DETAILS ABOUT ADAPTATION RESPONSES	LOCATION(S) WHERE ADAPTATION RESPONSES HAVE BEEN OBSERVED
Green infrastructure and sustainability planning	• Incorporating green infrastructure into new rural planning • Creating age-friendly communities • Designing more compact communities • Transitioning to renewable energy • Designing and implementing waste management plans based on best practices • Increasing government funding for low-carbon initiatives • Incorporating adaptation planning into municipal sustainability plans • Incorporating energy efficiency into building design • Developing strategic planning practices	BC, NB, NL, NS, NU, NWT, ON, YT and at the national-level
Community planning and zoning	• Incorporating climate change into new infrastructure planning • Undertaking floodplain and flood-risk mapping • Improving building standards by drawing on Indigenous Knowledge in building design • Undertaking community-based vulnerability assessments • Building walls and dykes • Strengthening transmission lines • Upgrading treatment facilities	AB, NB, NL, NS, NWT, PEI, QC and at the national-level

CATEGORIES OF ADAPTATION RESPONSES*	DETAILS ABOUT ADAPTATION RESPONSES	LOCATION(S) WHERE ADAPTATION RESPONSES HAVE BEEN OBSERVED
Community planning and zoning (continued)	• Implementing land-use restrictions and considerations • Incorporating “protect, accommodate, retreat or avoid” planning into land-use and zoning considerations	
Alternative transportation options	• Using rail transport and bicycle paths • Changing shipping times to correspond with changing climate conditions • Implementing changes to emergency transportation routes • Exploring new options to reduce the need for ice roads	NS, NWT, ON and at the national-level
Diversification of energy sources	• Connecting communities to central grids • Exploring the viability of renewable energy sources • Implementing collaboratively designed and installed hybrid renewable energy systems with diesel backup power • Developing stand-alone renewable energy systems	NU, NWT, YT, ON, BC, NL and at the national-level
Use of technology in adaptation	• Creating virtual replicas of fragile, remote and culturally valuable sites • Using multimedia technology to communicate risks from climate change	NB, NU

*Categories of adaptation responses are listed in the order of frequency that they are mentioned in the literature.

For rural and remote coastal communities, adaptations include revetment and building of new walls and dykes to safeguard against high-wave impacts and flooding (Vasseur et al., 2017; Hatcher and Forbes, 2015). Across Canada, rural and remote communities are converting their energy infrastructure by developing renewable energy sources and connecting communities to more centralized grids, where possible (Arriaga et al., 2017; Mortensen et al., 2017). Energy retrofits for homes and municipal facilities, as well as efforts to reduce reliance on fossil fuels for transportation, residential heating and cooking, are adaptation strategies that can also reduce GHG emissions, decrease the stress on fragile infrastructure, such as winter roads, and create cost savings (Climate Action Revenue Incentive Program, 2017; Yukon Legislative Assembly, 2017; Hatcher and Forbes, 2015).

The potential contribution of information and digital media technologies to adaptation in rural and remote communities is also being explored in various ways. For example, the Tantramar Planning District in New Brunswick has utilized information technology-based GIS maps and 3D flood animations to better communicate climate risks related to flooding and infrastructure failure to its residents (Lieske et al., 2014). In other regions, heritage and cultural buildings, trails and sites where physical infrastructure has already failed (or cannot be accessed without risk of injury) are being digitally reconstructed (*see* Section 3.2; Dawson and Levy, 2016).

Although communities are finding innovative ways to adapt, there are challenges that continue to impede progress on climate change adaptation. These include the high costs of infrastructure investment and an already existing infrastructure deficit. For communities with low-average incomes or a limited tax base, measures such as relocating houses due to erosion or building protection walls may not be affordable, so responses are often limited to temporary adaptations (Federation of Canadian Municipalities, 2018b; Vasseur et al., 2017). The lack of climate data, regional climate models, and inadequate and outdated flood-risk mapping, combined with a shortage of trained locals that can work with available climate change information, have led to difficulties in understanding and communicating climate-related risks (Mortensen et al., 2017; Dawson and Levy, 2016). Even where communities are able to access this information, short-term institutional memory can be a concern (Ford et al., 2017, 2013). For example, many northern communities often have high employee turnover rates. When there is a shift in management, large multi-year infrastructure projects may change, be cancelled or be significantly delayed (Ford et al., 2017). Communities require support in building adaptive readiness and establishing the governance, culture and social patterns (also known as “soft infrastructure”) needed to enhance understanding and make “hard” infrastructure investments possible (Pagano et al., 2018). These challenges will be familiar to most communities across Canada. Unfortunately, rural and remote communities often feel exacerbated impacts from these challenges due to their remote locations and the associated transportation and infrastructure limitations and costs.

Case Story 3.3: Adapting to transportation and service disruption in Nova Scotia’s ageing communities

Climate change and extreme weather events (e.g., high winds, storm surges and floods) are causing damage to critical transportation routes, which are necessary for delivering services and for responding to health and environmental emergencies. At the same time, the Province is projecting increased demand for emergency services due these factors, which is further complicated by the Province's ageing demographic (Climate Change Nova Scotia, 2018a, b; Krawchenko et al., 2016).

In response, provincial-level officials are working with planners and managers to develop strategies for rerouting transportation lanes and updating design standards to ensure that climate change is considered in new projects (Climate Change Nova Scotia, 2018a). Locally, municipal authorities are utilizing flood maps to warn future developers of projected risks from storm surges and associated flooding.

In Annapolis Royal, for example, flood maps identified that the town's fire hall is at risk of being cut off from the rest of the community in the event of projected storm surge flooding (*see* Figure 3.7). The fire department was able to use this information and adapt their emergency response plan, including purchasing a boat and redistributing rescue equipment throughout the community (Natural Resources Canada, 2015).

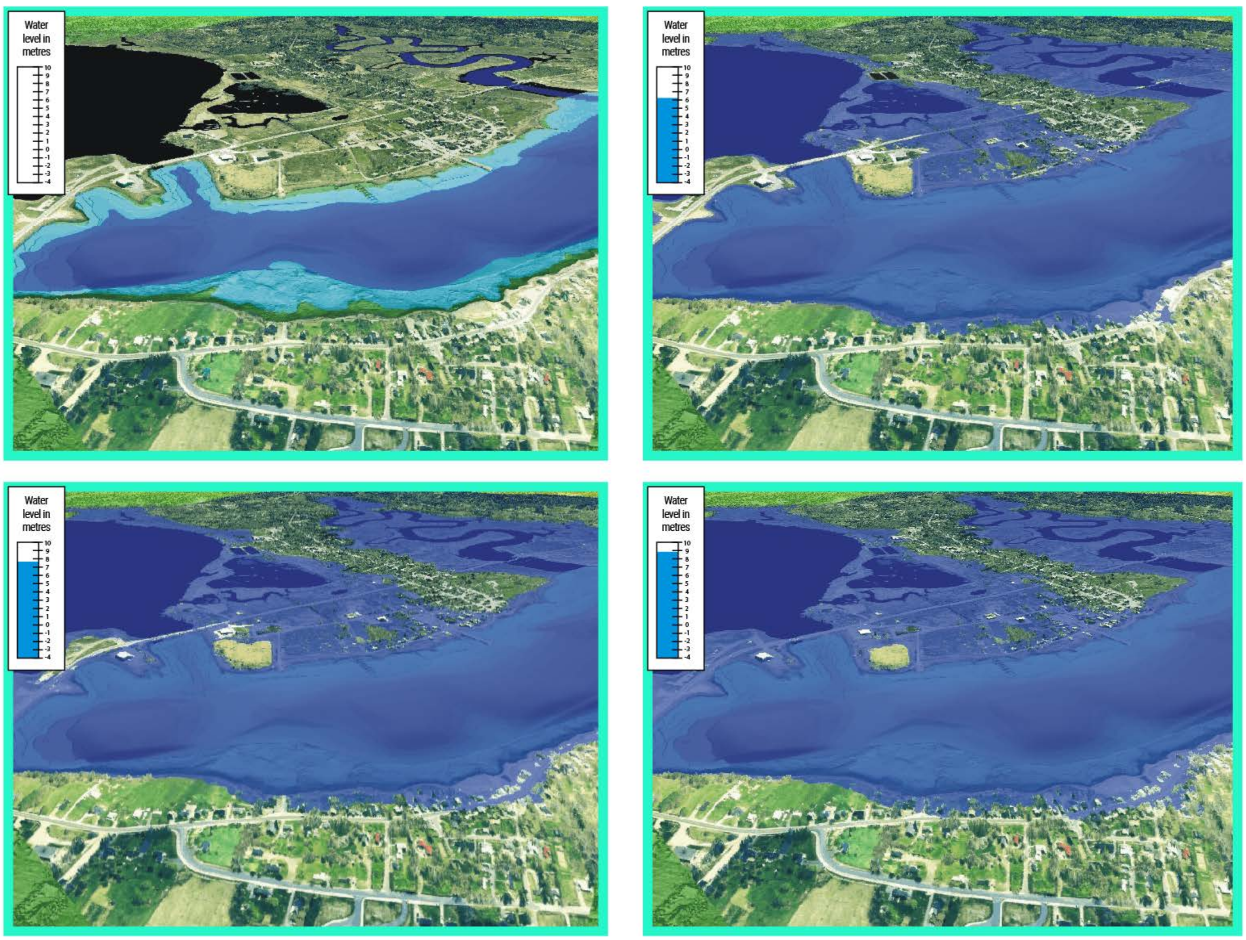

Figure 3.7: Flood-risk mapping in Annapolis Royal, Nova Scotia. Source: Webster et al., 2010.

3.6 Individual and community health and well-being are being negatively affected[2]

In rural and remote communities, health and well-being are strongly influenced by social, cultural and physical environments. Climate change is negatively impacting the health and well-being of individuals and communities, both directly and indirectly. Reducing risk, adapting to climate change impacts and realizing co-benefits from GHG emissions reduction present important opportunities for the health sector.

In rural and remote areas, many individuals and communities have a close connection to the environment; this connection has led to climate change affecting human health and well-being in many ways. Human health challenges linked to climate change in rural and remote communities include challenges with accessing healthy food and water; worsening of existing illnesses and development of new ones; injury or death caused by extreme weather events and changing conditions; and increasing mental health challenges connected to environmental uncertainties. Rural and remote communities have already begun to develop and carry out health-related adaptation plans. For them to continue adapting to the health impacts of climate change, it is important for decision-makers at all levels of government to consider community context, including age, gender, cultural and socioeconomic composition; draw upon and support local knowledge; and view human health within the social, cultural and physical environments of rural and remote areas.

3.6.1 Introduction

In rural and remote areas, human health and well-being are often influenced by the close connection that individuals and communities have to their social, cultural and physical environments (Cunsolo and Ellis, 2018; EPCCARR, 2018; Public Health Agency of Canada, 2017; IPCC, 2014). Many rural and remote communities, particularly Indigenous communities, rely closely on the land for their sustenance, livelihoods and cultural practices, which influences social determinants of health and well-being in a number of ways (Cunsolo and Ellis, 2018; EPCCARR, 2018; Cunsolo Willox et al., 2015; IPCC, 2014). As a result, climate change is leading to both direct (e.g., injury during extreme weather events) and indirect (e.g., poor nutrition caused by changing access to certain foods) effects on the health and well-being of individuals and communities (*see* Figure 2.8; Berner et al., 2016; EPCCARR, 2018; Durkalec et al., 2014; IPCC, 2014).

2 A modified version of this section was published as Kipp, A., Cunsolo, A., Vodden, K., King, N., Manners, S., and Harper, S.L. (2019). Climate Change Impacts on Health and Well-being in Rural and Remote Regions Across Canada: A Synthesis of the Literature. Health Promotion and Chronic Disease Prevention in Canada: Special Issue on Climate Change, 39(4): 22–126. https://doi.org/10.24095/hpcdp.39.4.02.

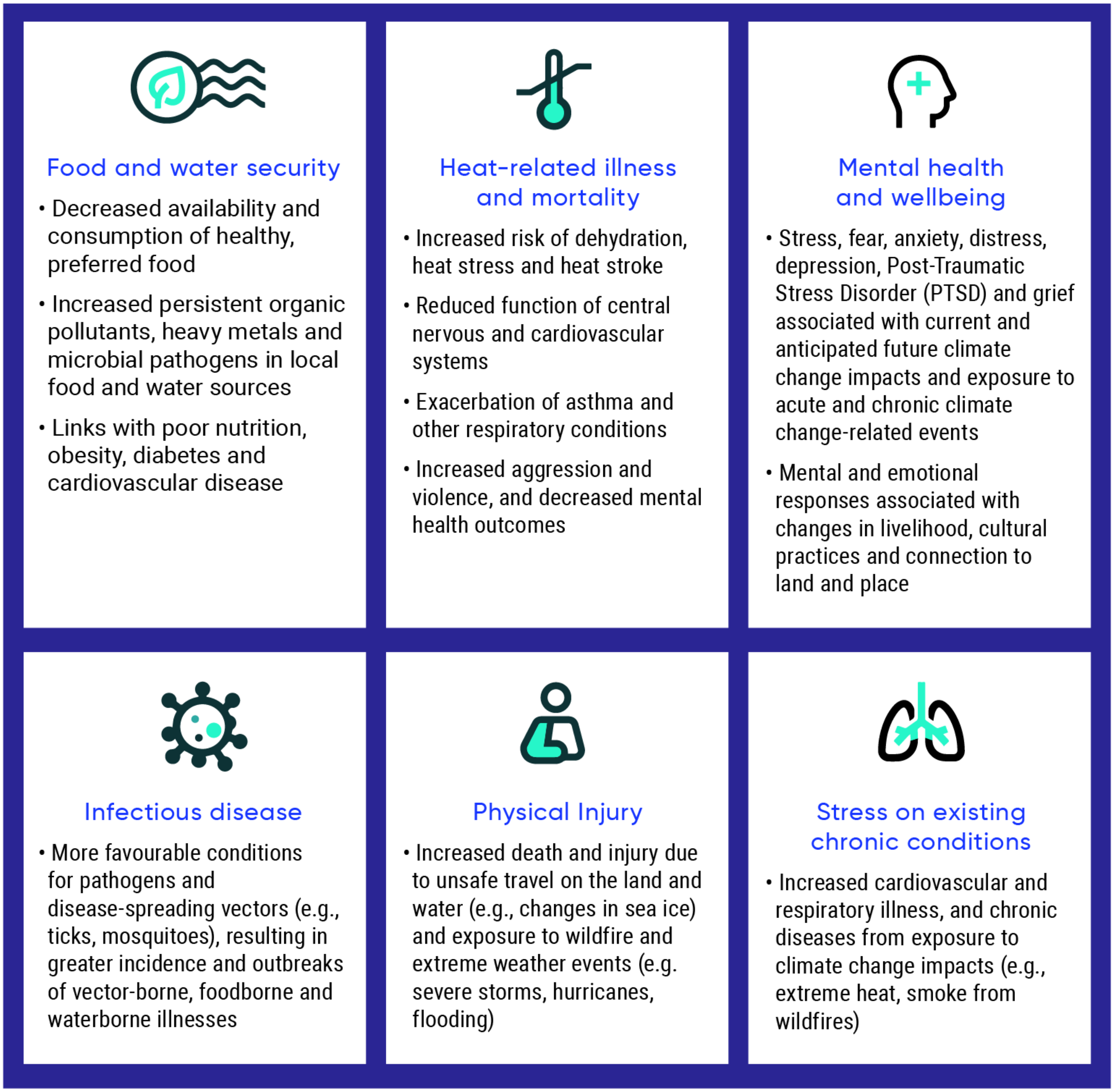

Figure 3.8: Climate change impacts on the health and well-being of individuals living in rural and remote communities.

Examples of negative impacts on individual and community health and well-being in rural and remote areas include increased prevalence and severity of extreme weather events (EPCCARR, 2018; Government of Saskatchewan, 2017; Rapaport et al., 2015; Ford et al., 2014; IPCC, 2014); changes to sea ice, vegetation, fish, wildlife and water (EPCCARR, 2018; IPCC, 2018, 2014; Clark and Ford, 2017; Ford et al., 2014); and weather and environmental uncertainties (Young et al., 2016; Cunsolo Willox et al., 2015; IPCC, 2014). Negative health outcomes associated with these changes include an increased prevalence of poor nutrition, obesity and diabetes (EPCCARR, 2018; Barbeau et al., 2015; Loring and Gerlach, 2015); vectorborne, waterborne and foodborne disease (EPCCARR, 2018; Loring and Gerlach, 2015; Ford et al., 2014); cardiovascular disease (Barbeau et al., 2015; Loring and Gerlach, 2015; Harper et al., 2011); respiratory issues (Dodd et al., 2018a, b); injury and mortality (Clark and Ford, 2017; Young et al., 2016; Ford et al., 2014); and mental health issues (Cunsolo and Ellis, 2018; Dodd et al., 2018a, b; Government of Northwest Territories, 2017; Cunsolo Willox et al., 2015; Statham et al., 2015). Characteristics of rural and remote areas that may increase sensitivity to these risks include their remote geography and limited transportation infrastructure; reliance on natural resources; under-resourced social and physical infrastructure; limited health system capacity due in part to there being fewer health professionals living and working in these areas; limited health infrastructure and access to health-sustaining resources; and reduced emergency response capacity (EPCCARR, 2018; IPCC, 2014).

Vulnerability to climate change is influenced by the intersection of demographic, social, cultural and political factors in rural and remote communities, as well as individual characteristics and circumstances (EPCCARR, 2018; Drolet and Sampson, 2017; Krawchenko et al., 2016; IPCC, 2014). Furthermore, the literature highlights indigeneity, age, gender and socioeconomic status (*see* Box 3.2) as key factors influencing individual and community vulnerability to climate change in rural and remote communities.

3.6.2 Availability of nourishing, accessible and preferred food and water sources

Many rural and remote communities have experienced changing access to and quality of food and water systems linked to environmental changes such as rising temperatures (Medeiros et al., 2017; Berner et al., 2016; Loring and Gerlach, 2015), changing precipitation patterns and increasing extreme weather events (Dodd et al., 2018a, b; Medeiros et al., 2017; Berner et al., 2016). For example, in many Northern remote First Nations and Inuit communities, climate change-related disruptions to sea ice, wildlife and vegetation impact the ability of individuals to hunt, fish and forage, leading to decreased consumption of healthy and culturally preferred local food and increased reliance on retail food (Dodd et al., 2018a, b; Government of Northwest Territories, 2017; Medeiros et al., 2017; Berner et al., 2016; Loring and Gerlach, 2015). Water security may also be challenging for rural and remote communities, where rising temperatures and more frequent extreme weather events can overwhelm fragile water treatment systems and interrupt the provision of safe drinking water (Medeiros et al., 2017; Berner et al., 2016) (*see* Water Resources chapter). Across Northern Canada—where many communities rely on surface water sources—changes to water levels, run-off, flow regimes and sediment accumulation can seriously affect drinking water availability and quality (Bakaic and Medeiros, 2017; Medeiros et al., 2017). Both food and water insecurity have been linked to negative health outcomes, including poor nutrition, obesity, diabetes, cardiovascular disease, acute gastrointestinal illness and mental health concerns (Berner et al., 2016; Harper et al., 2015; Loring and Gerlach, 2015; Ford et al., 2014).

3.6.3 Infectious disease and exacerbating existing chronic illnesses

Changing precipitation patterns, rising temperatures and increased frequency and severity of extreme weather can also exacerbate chronic illnesses and infectious diseases in rural and remote communities by increasing exposure to environmental contaminants and vectorborne, foodborne and waterborne diseases; putting enhanced stress on underlying chronic conditions (e.g., cardiovascular and respiratory illness) (Dodd et al., 2018b; Public Health Agency of Canada, 2017); and disrupting healthcare provision and chronic disease management (Cunsolo Willox et al., 2015). Research has also documented increased risk of waterborne disease in rural and remote communities due to weather-related contamination events (EPCCARR, 2018; Harper et al., 2015). Changing winds, ocean currents and rivers carrying environmental contaminants in the North may also lead to increased levels of persistent organic pollutants and toxic heavy metals in local food and water sources in remote polar regions (*see* Northern Canada chapter; Medeiros et al., 2017; Berner et al., 2016; Loring and Gerlach, 2015). Consumption of contaminants can result in many health concerns (Medeiros et al., 2017; Berner et al., 2016; Loring and Gerlach, 2015).

3.6.4 Increased risk of injury and mortality

Extreme and rapidly changing weather conditions—including heat waves, storms, droughts, floods and changing sea ice conditions—have had significant negative effects on the health of individuals living in rural and remote communities. For example, wildfires and associated health challenges—such as respiratory issues, mental health stressors and damage to critical health infrastructure—have been identified in forest communities across Canada as a threat to safety and well-being (*see* Case Story 3.4 and Sector Impacts and Adaptation chapter; Dodd et al., 2018a, b; Government of Northwest Territories, 2017; Government of Saskatchewan, 2017). Northern and remote communities have identified increased death and injury from changing weather and sea ice, leading to unsafe or unfamiliar travel conditions and reliance on technologies that can and do fail (e.g., snowmobiles breaking down, navigation systems failing) (Clark et al., 2016a, b).

3.6.5 Impacts on mental health and well-being

As environments change and people adapt to new and often less desirable conditions, the mental health and well-being of individuals living in rural and remote communities is also affected. For example, in Indigenous communities in rural and remote areas of Canada, individuals are often deeply connected to the land for their well-being; as climate change alters the environment, access to places and practices of cultural significance are often disrupted (Cunsolo and Ellis, 2018; Cunsolo et al., 2017; Cunsolo Willox et al., 2015; Ford et al., 2014). For Inuit in Nunatsiavut, for example, these changes have led to increased anxiety, fear, distress, anger, grief and depression related to changes to land-based activities, connection to land, and cultural identity (Cunsolo and Ellis, 2018; Cunsolo et al., 2017; Harper et al., 2015; Lament for the Land, 2014). Regional plans in Manitoba identify the potential loss of livelihoods associated with drought as a climate-sensitive mental health concern (Government of Manitoba, 2017). In Atlantic Canada, individuals have connected increases in the storm prevalence and severity in rural coastal communities and subsequent damage to important infrastructure with mental health challenges, which often differs by gender (Vasseur et al., 2015).

3.6.6 Adaptation responses and opportunities

Despite these challenges, focusing on climate change adaptation, risk reduction and realizing co-benefits from GHG emissions reduction presents an important opportunity for the health sector. Already, many rural and remote communities in Canada have begun to develop and implement health-related adaptation strategies (*see* Table 3.4). To support adaptation to the health effects of climate change, recommended changes to existing adaptation strategies include:

- using multiple knowledge systems that are specific to sociocultural contexts;
- addressing non-climatic factors impacting adaptation;
- utilizing innovative forms of technology;
- improving and integrating health surveillance with environmental monitoring;
- supporting sustainable development practices;
- enhancing awareness of risks and response;
- expanding knowledge of climate change impacts; and
- developing the capacity of the health sector to respond to climate change.

Ultimately, for rural and remote communities to continue adapting to the health impacts of climate change, it is important to consider specific local and regional, economic and geographic elements; support and draw upon existing expertise of individuals and communities in rural and remote areas in Canada; and continue viewing human health within the social-cultural and physical environments of rural and remote communities.

Table 3.4: Examples of existing and potential adaptation strategies to negative health effects of climate change in rural and remote communities across Canada

EXAMPLES OF EXISTING ADAPTATION STRATEGIES	REFERENCES
Introducing local food production systems	Government of Northwest Territories, 2017; Barbeau et al., 2015; Loring and Gerlach, 2015
Using experience-based knowledge of local communities to support community resilience	Cunsolo and Ellis, 2018; Cunsolo Willox et al., 2015; Ford et al., 2014
Developing community-based monitoring programs and research to gather data about environment and health to inform decision-making	Dodd et al., 2018; EPCCARR, 2018; Berner et al., 2016; Cunsolo Willox et al., 2015; Harper et al., 2015
Using Indigenous and local knowledge about the physical environment to support hazard avoidance and emergency preparedness	Clark and Ford, 2017; Young et al., 2016; Ford et al., 2014
Utilizing a social development approach—which involves health professionals, social workers and people working in caring professions that support those directly impacted by climate change—to strengthen community capacity	Drolet and Sampson, 2017
Fostering protective factors for physical and mental health through connection to land-based activities, cultural arts and crafts, and opportunities for bringing community together	Cunsolo et al., 2017
Using local knowledge, Indigenous Knowledge and/or scientific knowledge to adapt in a way that responds to specific local sociocultural contexts	Drolet and Sampson, 2017; Government of Northwest Territories, 2017; Berner et al., 2016; Ford et al., 2014

EXAMPLES OF POTENTIAL ADAPTATION STRATEGIES	REFERENCES
Eliminating social barriers to adaptation (e.g., poverty, inequality, housing concerns, etc.) and reducing non-climatic factors (e.g., chronic disease)	EPCCARR, 2018; Drolet and Sampson, 2017
Utilizing innovative forms of technology (e.g., telehealth, mobile monitoring applications, satellite imagery)	EPCCARR, 2018; Government of Northwest Territories, 2017
Improving public health surveillance and furthering monitoring programs	EPCCARR, 2018; Bakaic and Medeiros, 2017; Medeiros et al., 2017; Berner et al., 2016; Province of New Brunswick, 2016; Young et al., 2016; Barbeau et al., 2015; Durkalec et al., 2015; Ford et al., 2014
Supporting sustainable development practices (e.g., clean energy programs)	Drolet and Sampson, 2017; Government of Northwest Territories, 2017; Province of New Brunswick, 2016; Ford et al., 2014
Enhancing communication and awareness of risks and responses (e.g., lists of safe spaces, pamphlets regarding disease outbreaks, developing outreach strategies)	Dodd et al., 2018; EPCCARR, 2018; Government of Northwest Territories, 2017; Province of New Brunswick, 2016; Ford et al., 2014
Expanding knowledge of climate change impacts on health through research and investment, and sharing best practices for public health adaptation	EPCCARR, 2018; Government of Northwest Territories, 2017; Province of New Brunswick, 2016
Developing the capacity of health systems and emergency response to withstand and respond to climate risks (e.g., creating technical guidance and training courses, integrating climate change into medical and public health training)	Government of Northwest Territories, 2017; Young et al., 2016

Case Story 3.4: Coping with the health impacts of wildfire in the Northwest Territories

In the Northwest Territories, the summer of 2014 was one of the worst wildfire seasons on record, with prolonged smoke events and poor air quality. A study exploring the experiences of individuals in four subarctic communities found both short- and long-term effects of prolonged smoke exposure and isolation on their physical, emotional and mental health (Dodd et al., 2018a, b). While the prolonged smoke events were linked to extended time indoors and respiratory problems, interviewees also reported that their experiences of evacuation and isolation, as well as feelings of fear, stress and uncertainty, negatively impacted their mental and emotional well-being. In many cases, land-based activities were also impacted, with implications for individual and community well-being. Interviews also revealed that communities developed adaptation strategies that included educational workshops and physical activity programs to help reduce health risks. Nevertheless, there is a clear need for improved coordination and communication at the local and territorial level to better prepare for future wildfire events and reduce resulting health-related impacts.

3.7 Climate change is resulting in intangible losses and damages

Climate change impacts are leading to a wide range of intangible losses and damages in many rural and remote communities and areas, including the loss of identity, cultural continuity and sense of place. These intangible losses and damages are expected to be widespread and cumulative, and are critical to consider in climate change adaptation and policy.

In rural and remote areas, individuals and communities often have strong social and cultural connections to the environment. As a result, when the climate changes, individuals and communities in rural and remote areas can face impacts on their identity, culture and sense of place. Climate change is contributing to these losses and damages through several pathways, including shifts in cultural practices and identity; changes to the social fabric of rural and remote communities; and damages and destruction to both landscapes and spaces of cultural and social importance. Adaptation to these negative impacts has already begun as individuals and communities come to understand the links between climate change and identity, culture and place. As places of social and cultural importance shift in new ways, more research is needed on how these changes will affect the cultural and social fabric of communities, including cultural practices and identities, sharing and social ties, and place meaning and connection.

3.7.1 Introduction

Individuals and communities living in rural and remote communities and areas often have a strong social and cultural ties to their environments, which influence identity, cultural continuity and sense of place in numerous ways. Examples of this connection to place can be seen in remote Indigenous communities across Canada, where many individuals rely on the land for their culture and well-being, and practice land-based cultural activities including hunting, fishing and berry picking (Cunsolo Willox et al., 2015, 2013a, b, 2012; Harper et al., 2015; Loring and Gerlach, 2015; Pearce et al., 2015; Ford et al., 2014). It is also seen in rural areas throughout the prairies, where individuals in agricultural communities often have a strong heritage associated with farming and daily personal interactions with their land (McMartin and Merino, 2014). Place-based connection is also reflected in other rural and small-town communities—such as coastal and forest communities—where individual and group identities are often tied to local landscapes and reliance on natural resources (Dodd et al., 2018a, b; Vasseur et al., 2017).

Climate change and associated environmental impacts are leading to wide-ranging intangible losses and damages in many rural and remote communities (*see* Figure 3.9; Cunsolo and Ellis, 2018; Cunsolo Willox et al., 2015, 2013a, b, 2012). Specifically, recent studies have explored how climate change is disrupting cultural practices associated with the land (e.g., hunting, sewing, travelling on sea ice, etc.) (Cunsolo Willox et al., 2015, 2013a, b, 2012; Loring and Gerlach, 2015; Pearce et al., 2015; Ford et al., 2014); altering the inter-generational transmission of Indigenous Knowledge (Cunsolo Willox et al., 2015, 2013a, b, 2012; Durkalec et al., 2015; Ford et al., 2014); limiting access to places of cultural significance (e.g., hunting camps, sources of fresh water, etc.) (Government of Northwest Territories, 2017; Cunsolo Willox et al., 2015, 2013a, b, 2012); and damaging or destroying landscapes and sites of cultural and social significance (e.g., heritage and archeological sites) (Vasseur et al., 2017; Dawson and Levy, 2016). These climate-related changes are further exacerbated by non-climatic changes that also affect identity, cultural continuity and sense of place, which include ageing populations, rural to urban outmigration and the adoption of labour-saving technologies.

Although the impacts of climate change on identity, cultural continuity and sense of place are experienced differently by each individual and community, prominent themes include shifts in cultural practices and identity; the changing social fabric of rural and remote communities; and the damage and destruction of landscapes and sites of cultural and social significance.

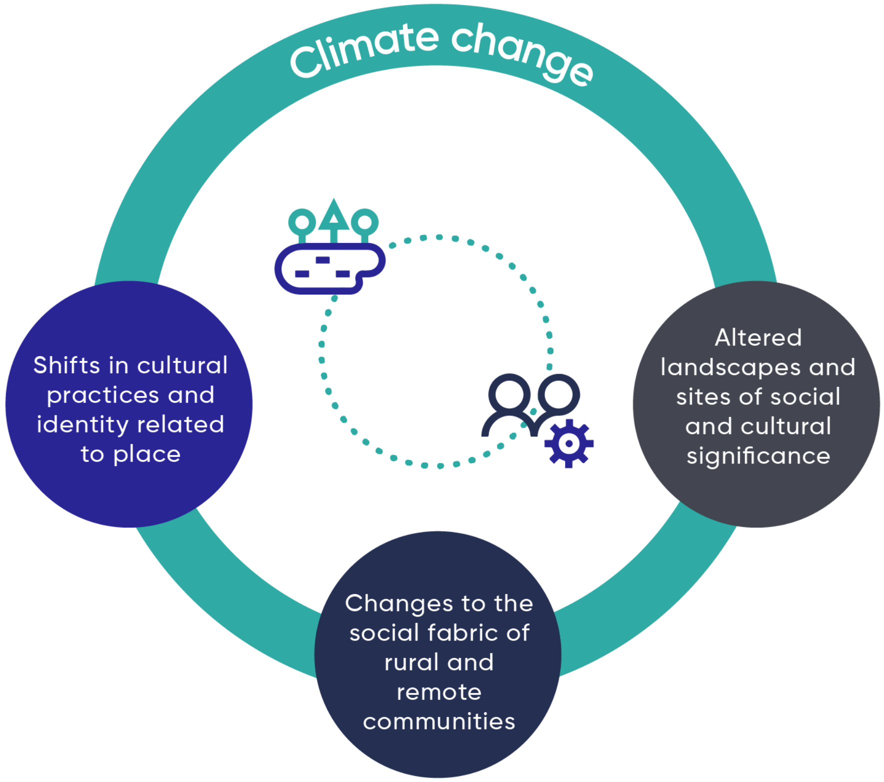

Figure 3.9: Summary of the intangible losses and damages of climate change on identity, cultural continuity and sense of place in rural and remote communities and areas in Canada.

3.7.2 Shifting cultural practices and identity related to place

The deep connections that individuals and communities in rural and remote areas share with their natural environments mean that many of their cultural practices are strongly connected to the land. For example, in many remote Inuit communities, spending time on the land and engaging with land-based activities hold important cultural and spiritual value; contribute to Inuit identity and cultural autonomy; and provide opportunities for the inter-generational transmission of knowledge (Clark et al., 2016b; Cunsolo Willox et al., 2015, 2013a, b, 2012; Durkalec et al., 2015; Harper et al., 2015; Pearce et al., 2015). Changing climatic conditions that alter the natural environment—such as changes to harvesting seasons, wildlife and plant species, traditional medicines and waterways—have the potential to disrupt cultural practices in a number of ways (Province of New Brunswick, 2016; Cunsolo Willox et al., 2015, 2013a, b, 2012; Harper et al., 2015).

Indigenous communities in rural and remote areas are at particular risk of experiencing cultural changes as a result of climate change. For example, climate change has impacted culturally important subsistence activities in many Indigenous communities, such as hunting, fishing, trapping, berry-picking, water collection, and subsequently the consumption of culturally significant food and water (Boulanger-Lapointe et al., 2019;

Archer et al., 2017; Government of Northwest Territories, 2017; Cunsolo Willox et al., 2015, 2013a, b, 2012; Harper et al., 2015; Pearce et al., 2015; Ford et al., 2014; Hanrahan et al., 2014). Such activities are altered as changes—including thinning sea ice, warming temperatures and increased storm prevalence—occur and impact the ability of Inuit to spend time on these changing landscapes (EPCCARR, 2018; Clark et al., 2016b; Cunsolo Willox et al., 2015, 2013a, b, 2012; Durkalec et al., 2015; Odland et al., 2015; Pearce et al., 2015; Ford et al., 2014).

Climate change is also impacting the ability of Indigenous Knowledge holders and Elders to use their knowledge on the land in rural and remote areas, since past knowledge becomes less applicable to current conditions (Government of Northwest Territories, 2017). These changes are altering place meanings and attachment, decreasing transmission of knowledge, eroding land-based skills and disrupting cultural identity and continuity (Clark et al., 2016b; Cunsolo Willox et al., 2015, 2013a, b, 2012; Durkalec et al., 2015; Pearce et al., 2015; Ford et al., 2014). There is limited research in a Canadian context regarding the impacts of climate change on the cultural practices of individuals and communities in rural and remote areas more broadly (e.g., in agricultural, coastal, forest and mountain communities). However, international literature indicates this is an important area of concern (Cunsolo and Ellis, 2018; Casanova-Pérez et al., 2016; Hall et al., 2016; Cunsolo Willox, 2012; Wolf et al., 2012). Thus, more research and engagement are needed to further explore the cultural dimensions of climate change in rural and remote communities across Canada.

3.7.3 Changes to the social fabric of rural and remote communities

Climate change is also influencing the social fabric of rural and remote communities, which includes the people living in these areas, interactions between people and the distribution and use of social spaces and services (Krawchenko et al., 2016). An example of climate change altering the social dimensions within communities can be seen in Saskatoon's Swift Current Creek Watershed, where drought associated with climate change has led to both economic and social stressors (McMartin and Merino, 2014). The socioeconomic structure of rural and remote communities—which may include a gendered-stratified workforce, declining economies, low levels of education, youth migration, distance from decision-makers and reliance on natural resources—may heighten the vulnerability of individuals and communities to the negative social effects of climate change (Vasseur et al., 2015). For example, in the rural coastal community of Ste. Flavie, Quebec, storm damage associated with climate change was identified as enhancing social stress in the community and corresponded with an increase in the out-migration of youth and families, as well as familial tensions and interpersonal conflict (Vasseur et al., 2015). In Rigolet, Nunatsiavut, shifts in weather, ice and seasonal patterns led to increased family and community stress, with concerns for increased family violence (Cunsolo Willox et al., 2013a).

In addition to disrupting cultural practices, climate change and associated stresses and challenges have resulted in the fragmentation of previously robust social networks and a loss of social capital in many rural and remote communities (EPCCARR, 2018; Medeiros et al., 2017). Rural and remote Indigenous communities, in particular, are disproportionately burdened by the social impacts of climate change, which exacerbate existing socioeconomic challenges such as issues with service provision and limited economic opportunities (EPCCARR, 2018; Picketts et al., 2017). In rural and remote communities more broadly, individuals with limited social capital and a lack of access to resources are often more at risk to the adverse effects of climate change (EPCCARR, 2018; Krawchenko et al., 2016).

Climate change in rural and remote areas has also influenced the social structure of communities in terms of gender roles. In agricultural communities in Saskatchewan, for example, a study found that environmental crises further entrench traditional conceptions of women's roles on farms, positioning men as the primary "farmer" and women as "caregivers, helpers and supporters," and assigning women less agency over climate change adaptation strategies (Women's Environment and Development Organization, 2018). Similarly, in forestry communities in Western Canada, women's marginal economic and social positions have influenced their vulnerability to changing climatic conditions (Williams et al., 2018; Reed et al., 2014). In Clyde River and Qikiqtarjuaq, Nunavut, climate change-related impacts to the accessibility of wildlife have resulted in shifts to women's primary economic roles in traditional food preparation and handicraft production (e.g., sewing of sealskin), with negative economic impacts for them and their communities, as well as important social and cultural impacts (Williams et al., 2018).

3.7.4 Loss and damage to landscapes and sites of cultural and social significance

Cultural landscapes and places of cultural and social significance, such as archeological and heritage sites, often contribute to a sense of place and cultural continuity for the individuals and communities connected to these places. In many rural and remote communities across Canada, climate change impacts—such as coastal erosion, changing precipitation patterns, increased forest fires and changes to freeze-thaw cycles—are contributing to the destruction of these sites, leading to irreversible loss and damages (Clarke and Clarke, 2018; EPCCARR, 2018). In rural and remote communities, such sites are at particular risk due to geographic locations, existing concerns with ageing infrastructure and limited resources for risk reduction and adaptation (EPCCARR, 2018). Furthermore, it is challenging to adapt to climate change by altering cultural landscapes or relocating heritage or archeological sites as their value is often tied directly to place; once these places are lost, they cannot be recovered (Clarke and Clarke, 2018; EPCCARR, 2018; Government of Canada, 2016).

In rural and remote coastal communities, climate change impacts such as sea level rise, loss of sea ice, storm surges, increased wind speeds and coastal erosion are directly damaging sites of cultural and social importance (Clarke and Clarke, 2018). In rural Nova Scotia, for example, a study examining climate change impacts on elderly populations found that flooding related to storm surges and changing precipitation patterns was negatively impacting social spaces and assets in the community that are important for daily routine and social engagement (Manuel et al., 2015). Increased winds and storm surges have also contributed to the deterioration of structures along the coast (e.g., lighthouses, piers), as well as natural heritage and landscapes (e.g., blown-down trees and loss of beaches and dunes) (Clarke and Clarke, 2018). Similarly, in Arctic and Subarctic regions, climate change impacts have destroyed rich archaeological records, natural and constructed heritage sites, and landscapes of cultural and social significance (Government of Northwest Territories, 2017; Andrews et al., 2016; Dawson and Levy, 2016).

In Northern regions, specific climate change concerns include the melting of sea ice and permanent snow pack; severe ice and snow storms; and a more dramatic rise in temperatures (Clarke and Clarke, 2018;

Government of Northwest Territories, 2017; Andrews et al., 2016). Fort Conger in Nunavut (*see* Section 3.2) and other heritage sites in the Arctic have been damaged by the accumulation of ice, snow and water; strong winds; increased freeze-thaw cycles; and the increased presence of fungi and subsequent rot supported by warming Arctic temperatures (Clarke and Clarke, 2018; Dawson and Levy, 2016). Changing temperatures, including both heat and cold extremes, also have potential to influence local extinction of wildlife and plant species that are important aspects of natural heritage (Clarke and Clarke, 2018). Changing climatic conditions have altered important landmarks used by Indigenous harvesters along travel routes and disrupted access to places of cultural, social, spiritual and emotional significance (Andrews et al., 2016). Although there is a gap in understanding about the full impacts related to the destruction of social and cultural sites throughout Canadian rural and remote communities, preserving these cultural assets can be seen as a symbol of resilience and community stability in rapidly changing times (Clarke and Clarke, 2018; Government of Northwest Territories, 2017).

3.7.5 Adaptation responses and opportunities

The intangible losses and damages of climate change on identity, cultural continuity and sense of place associated with climate change are widespread and cumulative, and will be critical to consider in climate change adaptation. Despite numerous challenges, adaptation to these negative impacts has already begun as individuals and communities in rural and remote areas identify how climate change impacts the interconnectedness and importance of identity, culture and place (*see* Table 3.5; Case Story 3.5). In many rural and remote Indigenous communities in Northern Canada, for example, the importance of drawing on Indigenous Knowledge, sharing networks and inter-generational transmission of knowledge has been highlighted as key to adaptation (Archer et al., 2017; Fawcett et al., 2017; Durkalec et al., 2015; Pearce et al., 2015; Statham et al., 2015). In rural prairie communities, agricultural producers have recognized the vital role of community, social and natural capital, and the need to respond collectively to climate change (Sauchyn, 2017). Moreover, in coastal communities in Atlantic and Northern Canada, where communities have identities that are strongly tied to cultural landscapes and sites of sociocultural significance, strategies to preserve and maintain at-risk sites are currently being explored (Clarke and Clarke, 2018; Government of Northwest Territories, 2017).

Table 3.5: Examples of existing and future adaptation strategies to address the impacts of climate change on identity, cultural continuity and sense of place in rural and remote communities across Canada

EXISTING ADAPTATION STRATEGIES	REFERENCES
Using technology to mobilize knowledge about sites of cultural and social significance that are at risk due to climate change can help gain support for preserving them.	Dawson and Levy, 2016

EXISTING ADAPTATION STRATEGIES	REFERENCES
Increasing technological capacity to address unpredictable conditions.	Archer et al., 2017; Fawcett et al., 2017
Community development programs focused on mobilizing local knowledge by drawing on local culture, skills and resources.	Drolet and Sampson, 2017
Using Indigenous Knowledge—including learned and land-based skills, experiences and group memory—to support flexibility and innovation in hunting (e.g., adapting seasonal cycles to hunt what is available); hazard avoidance; and emergency preparedness.	Fawcett et al., 2017; Cunsolo Willox et al., 2015, 2013a, b, 2012; Durkalec et al., 2015; Harper et al., 2015; Pearce et al., 2015
Social networks, community sharing, intercommunity trade and fostering social capital (e.g., sharing of food, equipment and knowledge when individuals are in need; delivering skills-based workshops).	Archer et al., 2017; Durkalec et al., 2015; Pearce et al., 2015; Statham et al., 2015
Building community resilience by creating a climate change action plan that draws from social networks, experiences, diversity, consensus building and culturally relevant tools.	Clarke and Clarke, 2018
Resurgence of Indigenous ceremonies, practices and values.	EPCCARR, 2018

POTENTIAL ADAPTATION STRATEGIES	REFERENCES
Integrating the geographical, social and cultural context of a community, as well as risks posed by climate change, in policy may improve relevancy and help to avoid maladaptation.	Drolet and Sampson, 2017; Ford et al., 2017; Krawchenko et al., 2016; Manuel et al., 2015
Inclusive design may contribute to recognizing the interdependency of social, economic and environmental considerations for adaptation, including social demographics (i.e., age, gender, socioeconomic status).	Drolet and Sampson, 2017; Rapaport et al., 2015; Vasseur et al., 2015
Developing and supporting adaptation strategies in Indigenous communities that are rooted in cultural values and Indigenous Knowledge can contribute to climate resilience (e.g., engaging community leaders and Elders).	Archer et al., 2017; Ford et al., 2017, 2014; Pearce et al., 2015; Gill and Lantz, 2014

POTENTIAL ADAPTATION STRATEGIES	REFERENCES
Developing new modes of knowledge mobilization through co-production of knowledge; creating adaptation tools and messaging that provide concrete practical advice; and creating incentives for implementation.	Ford et al., 2017; Reed et al., 2014
Establishing community-based environmental monitoring to encourage the protection of the land.	Government of Canada, 2016; Gill and Lantz, 2014
Incorporating culturally relevant and locally appropriate materials into education, programming and services; developing targeted education and knowledge transfer (e.g., teaching equipment and operability).	Clark et al., 2016a, b; Ford et al., 2014
Strengthening local autonomy in decision-making.	Ford et al., 2014
Strengthening land-based learning and inter-generational knowledge sharing.	Government of Northwest Territories, 2017; Ford et al., 2014
Considering cultural value and cultural identity in terms of long-term benefits to the community.	Clarke and Clarke, 2018
Establishing interdisciplinary teams to make decisions about preserving and maintaining heritage and sites of sociocultural significance.	Clarke and Clarke, 2018
Prioritizing excavating and collecting information from archaeological sites at greatest risk from climate change impacts.	Government of Northwest Territories, 2017
Potentially moving sites and structures of cultural and social significance to protect them from climate-related risks.	Clarke and Clarke, 2018; Government of Northwest Territories, 2017

A strong sense of culture has been identified as a protective factor moderating exposure to climate-related risks and plays a crucial role in influencing adaptive capacity (Cunsolo et al., 2017; Ford et al., 2014). Although many rural and remote communities have traditional cultural practices, culture is dynamic. For example, in Dawson Creek, British Columbia—where local cultural identities of self-sufficiency are closely tied to a heritage of farming—the community has used climate change adaptation to promote a renewed community identity around sustainability and energy independence, including through the creation of the Bear Mountain Wind Farm (Shaw et al., 2014). Ultimately, existing social capital in rural and remote communities, such as strong social networks and place-based knowledge systems, are key to adaptation (Furness and Nelson, 2016). As places of social and cultural significance shift in unprecedented ways, more research is needed on how these changes will alter the cultural practices and social fabric of communities.

Research indicates that intangible climate change impacts, such as adverse effects on culture or social capital, stem from direct impacts, as well as strategies for adaptation and GHG emissions reduction. In the movement towards clean energy, for example, the banning of a coal mine in the rural town of Atikokan, Ontario led to layoffs for approximately 90 individuals that worked for the power plant, with resulting adverse effects on the social fabric of the community (Dampier et al., 2016). Alternatively, as seen in the First Nations community of Fort Albany, Ontario, strategies for adaptation, risk reduction and GHG emissions reduction have promoted social cohesion and sharing (Barbeau et al., 2015). In this subarctic community, where local food systems have been introduced as a way of combating food insecurity, the act of gardening has strengthened family ties and provided space for knowledge transfer between generations (Barbeau et al., 2015). New forms of social networks can also help to strengthen social connections, such as using social media to identify individuals at risk during extreme weather events and to facilitate food and equipment sharing (Archer et al., 2017).

Case Story 3.5: Supporting Inuit wellness, strength, resilience and cultural continuity in Nunatsiavut, Labrador

Inuit throughout Inuit Nunangat (Inuit homelands) are at the forefront of a rapidly changing climate and environment. As a result, a priority of many Inuit communities is to develop strategies to support community wellness, foster livelihoods, maintain cultural values, enhance resilience, and preserve and promote cultural continuity. Responding to these stressors and needs, and building on previous research conducted in the region, the Inuit communities of Nunatsiavut, Labrador have been actively designing research and evidence-based programs to support Inuit wellness, strength, resilience and cultural continuity.

For example, communities in Nain and Hopedale established the Aullak, Sangilivallianginnatuk (Going Off, Growing Strong) program to bring youth and experienced harvesters together to support social and cultural connections, and community food security. The Inuit Community Governments of Rigolet, Makkovik and Postville in the Nunatsiavut region of Labrador designed and piloted the IlikKuset-Ilingannet (Culture-Connect!) program (Cunsolo et al., 2017; IllikKuset-Illingannet Team, 2014). This program was premised on the Inuit relational epistemology of piliriqatigiinniq ("working in a collaborative way for the common good") and united youth with adult mentors to learn cultural skills, including trapping, snowshoe-making, carving, art and sewing.

Both programs supported hands-on knowledge transmission; created new or enhanced relationships between and among the youth and mentors; revitalized cultural pride and well-being; promoted cultural preservation and promotion; and showed promise as a strategy for supporting cultural sustainability and resilience to change. This resonates with the growing emphasis on Indigenous-led programs that support cultural preservation, promotion, reclamation and resurgence, and contribute to a holistic understanding of, and strategies for, Northern sustainability.

3.8 Local participation in adaptation decision-making improves outcomes

Enhancing governance capacity and decision-making related to climate change adaptation in rural and remote communities requires access to additional resources, information and support. Decision-making processes related to adaptation programs and policy can be made more effective through greater participation of local residents and organizations, inclusion of local and Indigenous Knowledge, and consideration for the specific circumstances of rural and remote communities and areas.

Governments, civil society organizations, academic institutions and businesses are addressing climate change in various ways, including through planning, policy and program development. Access to resources, information and technical support have enhanced adaptive capacity in some rural and remote communities; however, further support in the form of region-specific information, trained personnel such as planners and engineers, and funding sources are needed to address adaptation planning and implementation requirements, and limited local governance capacity. Coordination among actors—including government agencies at all levels—is also critical, while recognizing the need for place-based planning and responses.

3.8.1 Introduction

Rural and remote governance structures at multiple levels and across many sectors are facing challenges due to a changing climate (*see* Box 3.5), and are attempting to respond to these challenges and associated opportunities (Northwest Territories Legislative Assembly, 2018; Government of Canada, 2017; Hurlbert and Pittman, 2014; McMartin and Merino, 2014). Climate change impacts are affecting not only planning and policy, but also infrastructure and service delivery—particularly during emergencies and related to community and economic development, and the governance of lands and natural resources.

Box 3.5: The governance of adaptation

Governance is understood as the ways in which government and non-government actors organize themselves to respond to societal problems or new opportunities, including establishing and shaping formal and informal institutions to help guide such responses. Adaptation governance, more specifically, refers to the combined efforts of these various actors to adapt to climate change. Efforts include the institutions, policies, plans and strategies that are formed or used to tackle adaptation issues, ideas of how adaptation should be undertaken and governed, and decisions that are made—such as the identification of problems, and mechanisms used for implementation and enforcement (Huitema et al., 2016).

3.8.2 The need for a collaborative approach to governance

All levels of government are playing a role in responding to climate change within rural and remote communities (*see* Table 3.6). Current research highlights the importance of federal, provincial and territorial levels of governments, as well as Indigenous governments and organizations, and international intergovernmental initiatives in supporting rural and remote communities in their adaptation efforts. It is essential that institutionalized knowledge and research institutions meaningfully engage with local and Indigenous Knowledge holders and citizen scientists to better understand and respond to the challenges of climate change. Creating and setting new policies, legislation, funding, training and technical assistance programs are important tools used by these governments and organizations (Government of Northwest Territories, 2016; Hurlbert and Pittman, 2014).

Table 3.6: Governance processes related to climate change adaptation in rural and remote communities across Canada

ADAPTATION GOVERNANCE PROCESSES	LOCATIONS OBSERVED*	LEVELS OF GOVERNMENT INVOLVED*	OTHER ACTORS INVOLVED*
Policy-setting and implementation: Legislative changes; devolution of planning powers to municipalities; development of community charters; social policy development; climate change strategic frameworks; and the Pan-Canadian Framework on Clean Growth and Energy.	BC, NS, NU, ON, SK and at the national level	Local/municipal, provincial/territorial, federal, international	Academic/research, NGOs (non-governmental organizations)
Planning: Climate change adaptation planning; waste management plans; development of disaster risk management strategies; transportation planning; energy planning; integration of health planning and climate change watershed planning; and community planning.	BC, NB, NL, NWT, ON, QC, YT and at the national level	Local/municipal, Indigenous, Tribal Council, provincial/territorial, federal, international	Academic/research, NGOs, private sector, industry

ADAPTATION GOVERNANCE PROCESSES	LOCATIONS OBSERVED*	LEVELS OF GOVERNMENT INVOLVED*	OTHER ACTORS INVOLVED*
Program development and implementation: Implementation of adaptive management programs; pilot adaptation initiatives; training; supporting beneficial management practices; and other actions.	AB, BC, MB, NWT, ON, QC, SK, YT and at the national level	Local/municipal, Indigenous, provincial/territorial, federal, international	Academic/research, NGOs, private sector, industry
Information gathering and sharing: Development of risk assessment tools; information gathering; monitoring and evaluation; information sharing; research; and public engagement.	BC, MB, NB, NL, NWT, PEI, QC, SK and at the national level	Local/municipal, Indigenous, provincial/territorial, federal, international	Academic/research, NGOs, private sector, industry

*As noted in recent literature that has been identified and reviewed.

Civil society organizations, including NGOs, as well as research institutions and the private sector are also playing crucial roles. Many governments are facilitating and fostering relationships with NGOs to assist with the implementation of adaptation initiatives (Drolet and Sampson, 2017; Caldwell, 2015). Civil society organizations, along with Indigenous and municipal governments, are taking on important roles in adaptation by providing place-based solutions to climate change impacts at the local and regional level. One way that adaptation is being addressed is through collaborative watershed management, where a range of different stakeholders (e.g., governments, local public health, local conservation, landowners, community groups, etc.) work together to protect a transboundary area (Healthy Lake Huron, 2019). For example, in British Columbia, watershed organizations such as the Similkameen Valley Planning Association, Fraser Basin Council, Nechako Watershed Alliance and Columbia Basin Trust are working with governments at all levels and post-secondary, business and community partners to conduct climate change- and adaptation-related research, planning, education and monitoring (*see* Case Story 3.6; Horning et al., 2016a, b; Picketts et al., 2017).

Local governments and organizations in rural and remote areas—in collaboration with provincial, territorial and federal partners—are developing community-, regional- and sector-specific adaptive management plans and strategies to address climate variability and uncertainty (Warren and Lemmen, 2014; McMartin and Merino, 2014). For example, recent projections include increases in average temperature, climate variability, droughts and soil degradation in the prairie region (Bush and Lemmen, 2019), creating great uncertainty for agricultural communities. Acknowledging that adaptation depends on both the availability of resources and the capacity to utilize them, the Canada-Saskatchewan Farm Stewardship Program and Farm and Ranch Water Program were created to provide support to agricultural producers to adapt to environmental risks (Hurlbert and Pittman, 2014) (*see* Case Story 3.2). Similarly, in British Columbia, the Agriculture and Food

Climate Action Initiative was created by the BC Agriculture Council in cooperation with federal and provincial governments to develop tools and resources that will help the agriculture sector to be more resilient in dealing with climate change (BC Agriculture and Food Climate Action Initiative, 2018).

Climate change is straining the ability of existing governance structures and institutions to respond to the social, economic, cultural and environmental impacts faced by many rural and remote communities. In light of these challenges, civil society organizations, research institutions and local businesses have emerged to fill vital gaps. Their efforts are helping to turn research, funding and expertise into practical adaptation planning within communities. To this end, rural and remote communities are engaging in a number of formal and informal governance processes that include multiple agencies in adaptation planning, policies and programs to enhance local decision-making capacity, public engagement and action (Blanco et al., 2015; Schroth et al., 2015).

3.8.3 Responding to governance challenges

Climate change poses significant governance challenges. Although collaborative forms of adaptation governance are increasingly recommended, they require considerable intergovernmental and multi-stakeholder coordination efforts (Auditor General of Canada, 2018). Responding to climate change in rural and remote communities is increasingly complex, as the associated roles and responsibilities are spread across multiple agencies, organizations and levels of government. Uncertainties related to ownership and responsibility for service delivery may have sometimes resulted in an inability to adequately respond to environmental emergencies across the country, such as floods and heat waves, which is indicative of the challenges associated with coordination (Caldwell, 2015).

There is also concern that current forms of adaptation governance may further encourage or support the downloading of additional responsibility from senior levels of government to already stretched local institutions, without their agreement and/or additional required resources. For instance, many of the provincial mechanisms for addressing climate-related disasters in rural and remote communities have been structured to rely heavily on local volunteers and community members—many of whom may come from vulnerable or marginalized populations and face heightened risks associated with natural disasters, unemployment or even forced migration, for example, and may already be dealing with personal impacts related to livelihoods, healthcare and housing (Drolet and Sampson, 2017; Caldwell, 2015). For Indigenous communities, the development of collaborative governance approaches requires particular care, trust-building and acknowledgement of Indigenous rightsholders, given Canada's colonial legacy and its impacts on relationships and adaptive capacity (Archer et al. 2017; Pearce et al., 2015).

In addition to overcoming institutional legacies and the need for coordination, other challenges exist in developing local adaptation strategies (*see* Table 3.7; Climate Action Revenue Incentive Program, 2017; Yukon Legislative Assembly, 2017). Incomplete information or lack of research and evidence represents an ongoing challenge for rural and remote communities that are hoping to begin adaptation planning. While some communities in these regions have created partnerships with academic institutions and other organizations to address gaps in data collection, problem identification, monitoring and evaluation of adaptation options, these institutions are often located outside of rural and remote areas. As a result, these institutions are not always easily accessible to citizens residing in rural and remote areas who are seeking to understand, respond and adapt to climate change impacts (Harneet and Lantz, 2014). Further complicating the issue is the need for locally appropriate information, which is often lacking.

Table 3.7: Challenges related to adaptation governance in rural and remote communities across Canada

CATEGORIES OF GOVERNANCE CHALLENGES	LOCATION(S) OBSERVED*
Policy and planning: Problem identification; existence of pressing socioeconomic issues; delivery of services and support; inability to maintain infrastructure (e.g., winter roads); management of change and community support systems; lack of regional regulations; development of local adaptation strategies; and integration of climate change into spatial planning.	BC, ON, NS, NWT, NU, SK, YK
Responding to climate-related emergencies: Responding to floods and changing flood risks; developing strategies for combating wildfires; and responding to environmental emergencies.	BC, NB, ON, PEI, QC
Resources and capacity: Providing technical and financial training; providing funding and subsidization opportunities for local adaptation efforts; stimulating private sector investments; competing for resources at all levels; high costs of adaptation and responding to natural disasters; and measuring the adaptive capacity of communities.	AB, BC, MB, NB, ON, NL, NWT, PEI, QC, SK, YT and at the national level
Trade-offs between adaptation, GHG emissions reduction and resource development: Adaptation vs. GHG emissions reduction; carbon taxation; and reliance on natural resource sectors.	BC, YT
Intergovernmental coordination: Clarification of roles and responsibilities; increased cooperation between jurisdictions; fragmented communication between government departments; and water and watershed governance.	BC, ON, NL, NU, SK
Communicating risks: Communicating complexities of climate change to the public.	BC, QC

* Locations noted in recent literature that has been identified and reviewed.

Another challenge that is facing institutions responding to climate change in rural and remote communities is balancing the need to adapt to changing environmental conditions with meeting nationally set GHG reduction targets. In many cases, GHG emission reduction targets are being weighed against economic benefits that are derived from resource development (Drolet and Sampson, 2017). When planning adaptation, the need to remain competitive while adhering to international commitments to reduce emissions and to protect against environmental degradation can further stress already stretched resources and human capacity (Government of Canada, 2017, 2016; Yukon Legislative Assembly, 2017; Furness and Nelson, 2016; Government of Ontario, 2016; Province of New Brunswick, 2016; The Ontario Bar Association, 2015). Oxford County, Ontario has incorporated national GHG emissions reduction targets into its sustainability plan, and goes further to address some of the regional challenges it is experiencing, with the aim of building a healthier environment and population, and a vibrant economy that supports sustainability (Oxford County Council, 2015).

Regional case studies provide insights into how factors such as human and financial resources relate to local governance capacity and climate change (*see* Case Story 3.6). Regional governance responses to climate change, such as watershed-scale efforts in British Columbia, point to the necessity of place-specific adaptation partnerships in policy and action (Breen and Rethoret, 2018). In another example, the Qalipu First Nation in Newfoundland has been conducting a regional assessment of climate change impacts on services, health and infrastructure, which will help communities adapt. This ongoing assessment is using information collected through interviews with residents, public data and GIS, and examining issues such as water quality, vulnerability and potential for flooding in nine communities (Sullivan, 2018). Support to strengthen asset management capacity, such as that provided by the Federation of Canadian Municipalities (FCM) to Municipalities Newfoundland and Labrador (the provincial-level municipal association), is vitally important in a province where just one quarter of municipalities have more than one staff person for all municipal responsibilities (Parewick, 2018; Irvine et al., 2016). The FCM has provided critical support to such initiatives through the Municipalities for Climate Innovation Program, which assists communities in both reducing GHG emissions and adapting to climate change through c apacity building (Federation of Canadian Municipalities, 2018b; Infrastructure Canada, 2018).

Case Story 3.6: Co-constructing and building rural adaptation capacity

The impacts of climate change are already being felt in the rural Kootenay Region of southeast British Columbia and are expected to increase over time. Impacts include increases in the number and severity of wildfires and extreme weather events, as well as changes in the landscape. These impacts are also affecting infrastructure, emergency planning and community development.

Local governments are front-line responders when it comes to adapting to climate change. However, in the Kootenays, like elsewhere, they face challenges including human and financial capacity limitations, reliance on natural resources, limited jurisdictional authority and a lack of appropriate supports and data. In this light, climate change can feel like an insurmountable hurdle. However, Kootenay communities also have unique, place-based assets that have been used to strengthen adaptive capacity, particularly in the form of local expertise and partner organizations like the Columbia Basin Rural Development Institute (RDI), a community college-based research institute, and the Columbia Basin Trust (CBT), a regional trust (Columbia Basin Rural Development Institute, 2017; Columbia Basin Trust, 2015).

In 2014, the RDI partnered with the CBT to explore how communities could measure their progress in adapting to climate change, resulting in the State of Climate Adaptation and Resilience in the Basin (SoCARB) indicator suite. SoCARB took a comprehensive view of adaptation by linking climate change indicators to indicators of environmental and community impacts, which were in turn linked to indicators of adaptation actions and capacity. SoCARB was also rooted in the regional context, with the indicators being organized into five "adaptation pathways" (each representing a regional adaptation priority) (Columbia Basin Trust, 2015).

In 2016, the RDI initiated a pilot of the SoCARB indicators, with the intention of developing a replicable approach to adaptation measurement. RDI collaborated with the municipalities of Kimberley and Rossland, as well as the Regional Districts of Central Kootenay and East Kootenay. The project team included local government staff, elected officials, college researchers, a co-op student, a graduate student, two liaisons and advisors with climate change expertise.

The team brainstormed how to operationalize the SoCARB approach, particularly in light of limited time and money. A review of the adaptation pathways against local priorities resulted in a custom list of indicators for each community. Researchers, local government staff and students gathered the related data. Liaisons and staff guided the analysis, based on what they needed to know. The resulting community reports were developed to support each community in identifying and tracking key indicators, and using the results to inform their actions and related plans. A graduate student conducted an evaluation of the process, providing an external reflection.

This project is one example of an adaptation project that was locally driven, place-specific and collaborative. The partnerships were critical to the success of the project, with each team member playing a role in ensuring that the approach and results were rigorous, adaptive and locally relevant (Columbia Basin Rural Development Institute, 2017).

The RDI's work on rural climate change adaptation continues to grow and evolve. For more information, visit www.cbrdi.ca.

3.9 Moving forward

3.9.1 Knowledge gaps and research needs

There has been substantial work to better understand and adapt to climate change in Canadian rural and remote communities, although many knowledge gaps remain. For instance, challenges in accessing, interpreting and applying regional climate trend data at the scales needed for decision-making are important obstacles to better understanding climate change and incorporating this understanding into all levels of governance. Gaps in the collection and analysis of local data result in a limited ability to understand and plan appropriate responses for reducing vulnerability and risk related to projected climate change impacts in communities. Other knowledge gaps include the need for information on changes in the behaviour of forest fires; baseline data about community-level water supply; identifying threats from pests, pathogens, weeds and invasive species; and the need for new or updated flood risk mapping. In particular, improved knowledge of how shoreline shape may relate to coastal flooding in different contexts would also be useful for examining vulnerability at the local level, and for informing planning and related policies (Vasseur et al., 2017). Increased knowledge of strategies for responding to these threats and to environmental emergencies is also needed (Furness and Nelson, 2016). Further studies are also needed related to climate change impacts in rural sectors such as aquaculture, mining, oil and gas, and tourism in Canada (Weatherdon et al., 2016). Overall, scientific challenges related to climate change modelling and analysis for rural and remote communities include the limited availability of locally relevant data, knowledge and expertise, as well as the associated financial resources.

While it is evident that climate change is having impacts on human health in rural and remote Canada, the extent to which these impacts are, and will continue to be, felt is not fully understood (Kipp et al., 2019; Furness and Nelson, 2016). For example, changing dynamics related to travel on ice and land have the potential to contribute to injuries experienced during transit, as landscape features become exposed, temperatures rise and ice becomes thinner. However, understanding how these changing environmental conditions may be affecting injury rates, particularly in Inuit regions that often see higher rates of unintentional injury, is still lacking (Durkalec et al., 2015). Furthermore, research is needed to determine the extent to which injuries related to climate change differ based on individual capacities, activities and roles in communities (Clark et al., 2016a, b). There is very little information available about how different social dynamics (e.g., factors such as gender, age and culture) within communities contribute to their overall capacity and ability to adapt to climate change (Reed et al., 2014). Research related to changes in demographics and social cohesion is key to understanding social capacities in rural and remote communities.

There are also knowledge gaps in the understanding of the mental health ramifications of climate change, which are closely related to the impacts of climate change on physical and environmental health (Middleton et al., 2020; Cunsolo Willox et al., 2013a, b). Topics like ecological grief and anxiety (Cunsolo and Ellis, 2018) require further study to better understand their impact on different population groups. The mental health of Indigenous people and others who rely closely on the land for their culture, sustenance and livelihoods (e.g., farmers and fishers) is a particular area of concern. These groups are especially exposed to climate change impacts, although research related to their mental health and well-being in the context of climate change is limited (e.g., Middleton et al., 2020; Dodd et al., 2018; Cunsolo Willox et al., 2015; Harper et al., 2015; Cunsolo Willox et al. 2013a, b). Research on understanding how intangible losses affect different people and communities, and how best to account for these losses is similarly limited (Tschakert et al., 2019; Tschakert et al., 2017). Indeed, there is a general need to better examine the human component of climate change throughout rural and remote communities in Canada (Akkari and Bryant, 2016; Statham et al., 2015).

Research on place-based monitoring of environmental, health and social changes related to climate change and adaptation is urgently needed. More research is also needed to explore the impacts of environmental shifts on knowledge systems, language and cultural practices in rural and remote communities. Furthermore, for rural and remote Indigenous communities, mental health, sense of place and sociocultural well-being are topics that vitally require further inquiry (Durkalec et al., 2015). Despite considerable research in recent years on how climate change interacts with Inuit communities, little research has explored the long-term responses to, and experiences of, climate change in Inuit communities (Archer et al., 2017). It is also important to identify ways for better defining and including local and Indigenous Knowledge in adaptation research and action.

The importance of community governance and values in relation to adaptive capacity suggests that further questions on these issues may need to be addressed (Furness and Nelson, 2016, 256). To assess their effectiveness and efficiency in implementation, plans and policy changes aimed at addressing the issues discussed here need to be closely analyzed. Two-way communication and knowledge transfer on the nature of climate change and related policy is key to ensuring the successful implementation of such policies. Another knowledge gap relates to the effective transfer and mobilization of climate change knowledge (Akkari and Bryant, 2016; Burch and Harris, 2014; Larsen et al., 2012). In general, more research is needed to determine the most effective ways for making local and regional climate change data available, as well as information on potential impacts and adaptation options. For instance, how climate change affects decision-making for farmers is an area in need of further research, and it has been suggested that focused and regularly timed reports on climate change to farm decision-makers would be useful for adaptation and response (Akkari and Bryant, 2016). Better understanding the nature and culture of climate denial within the Canadian context might also allow for the development of more effective and targeted educational tools to assist in increasing knowledge and action around adaptation, risk reduction and GHG emissions reduction in rural and remote communities (Furness and Nelson, 2016; Stoddart and Sodero, 2015). Finally, there is a need for a better understanding of the drivers and perspectives that drive people to learn about climate change, of how effectively and quickly that learning is happening and of the impacts and potential uses of technology for learning and knowledge sharing in rural and remote communities (Archer et al., 2017; Fawcett et al., 2017).

3.9.2 Emerging issues

Throughout these sections, some of the emerging climate change-related issues facing rural and remote communities in Canada have been outlined. There are significant safety concerns for communities, not only in terms of the potential impact of extreme weather events, but also related to the impacts of gradual changes in climate. From a health perspective, it is also important to better understand how climate change will affect mental health in communities, as mentioned above. Rural and remote communities are undergoing multiple social and cultural changes throughout Canada, and researchers are only beginning to understand how these intersecting changes interact with climate change and the ability of communities to adapt. For example, although some Arctic water fish stocks are growing as a result of increases in ocean temperature, there are concerns that potential new opportunities related to this may be offset by factors such as rising competition for these new resources; increased presence of industrial fishing; reduced availability of traditionally harvested species; limited management controls; and issues concerning Indigenous access and sovereignty over fish stocks in their homelands (Bindoff et al., 2019; Meredith et al., 2019; Weatherdon et al., 2016). Changes are also happening in communities related to GHG emissions reduction efforts—including shifts to low-carbon economies and a resulting growth in renewables and biofuels—which pose different challenges and opportunities, and require attention to ensure they are developed in sustainable ways and that rural and remote communities are provided with the necessary support for economic transition.

Climate change will require continued infrastructure upgrades and enhancements to services at the local level across Canada for adaptation efforts to be successful. However, these requirements come at the same time as growing infrastructure deficits, service withdrawals and demographic shifts in rural and remote communities. Governance has likewise become a core consideration in ensuring effective coping and adaptation in response to climate change. As with infrastructure and services, governance for climate change adaptation is evolving and will require local support, as community leaders continue to struggle with increasing demands from stakeholders, but with decreasing resources to meet those demands. Governance entails a complex series of relationships between different agencies across all levels of government, as well as other organizations. Communication and coordination are key to successful governance, as is ensuring that communities can lead adaptation activities with place-specific solutions. Indeed, national-level and international-level climate policy, programs and measures may not always be well suited to the circumstances of rural and remote communities. Understanding these factors and evolving dynamics will be essential to future success; they are emerging issues worthy of ongoing attention.

3.10 Conclusion

Rural and remote regions in Canada are experiencing significant climate change impacts. They are home to residents, businesses and organizations that tend to rely on climate-sensitive natural resources and ecosystems for their cultures, livelihoods and well-being, while also having fewer financial, human and formal institutional resources with which to respond than their urban counterparts (*see* Table 3.8 for short, medium and long-term risks of climate change for rural and remote communities). Despite these challenges and risks, rural and remote regions continue to display strong resilience, drawing upon assets such as strong informal economies, social networks, and connections to place, community and culture. Place-based knowledge systems (e.g., local and/or Indigenous Knowledge) and lived experience have been key to understanding the impacts associated with climate change, as well as for developing successful responses and adaptations.

Adaptation strategies related to local economies have included planning for economic change and protecting traditional economies through technology, capacity building and changing land practices. These efforts have been necessary responses to the effects of changing sea ice conditions, warmer temperatures and drought on economic sectors, such as agriculture, forestry, fishing and tourism, as well as subsistence activities, such as hunting and gathering, which are vital to livelihoods and economic well-being in many rural and remote regions.

Rural and remote transportation networks and services also continue to face a greater risk of failure and disruption from projected increases in extreme weather events, with coastal communities being particularly vulnerable to environmental emergencies disrupting infrastructure and activities necessary for carrying out daily life. As a result, rural and remote communities and regions are incorporating climate change considerations in their community planning and design and beginning to reinforce, rebuild and reimagine their built environments.

These climate-related changes directly and indirectly impact the physical and mental health and well-being of individuals and communities. Focusing on climate change adaptation, as well as realizing co-benefits from GHG emissions reduction and risk reduction, present an important opportunity for the health sector. Climate change and its associated impacts are leading to wide-ranging intangible losses and damages in many communities, including loss of identity, cultural continuity and sense of place. These effects are expected to be widespread and cumulative, and are critical to consider in climate change adaptation and policy.

Despite the tremendous resilience of rural and remote communities, their adaptive capacities are increasingly strained by ongoing and often rapid social-ecological change. Increased funding to support local adaptation planning and initiatives, information and support is needed to enhance governance capacity and decision-making related to climate change adaptation in these regions. Furthermore, the diverse range of impacts and potential costs of adaptation will require communities to prioritize actions, and mainstream adaptation actions and related investments. Greater inclusion will be essential along with provincial and federal level planning, programs and policy that take into account the specific circumstances of rural and remote regions.

Table 3.8: Climate-related risk in rural and remote communities across Canada

NEAR	MEDIUM	LONG-TERM
Place-based knowledge systems		
• Changing sea ice conditions, warmer temperatures and drought are posing immediate risks to local and Indigenous Knowledge in the agriculture, forestry, fishing and tourism sectors, as well as to subsistence activities such as hunting and gathering.	• Changing weather stressors are affecting agricultural production and local, land-based knowledge systems. • Climate change is creating an ongoing challenge for Indigenous Knowledge Systems that are founded on skills and knowledge related to the land, and which form the basis for safe practice and hazard avoidance while out on the land.	• Threats to long-term and ongoing relationships between people and their natural environments. • Disruptions to the social fabric and cultural identities of rural and remote communities.
Livelihoods and economy		
• Immediate impacts to infrastructure that livelihood rely on due to severe weather, thawing permafrost, droughts, flooding, storm surges and erosion. • Current observed changes in fish and wildlife species and related impacts. • Reduced accessibility of traditional food sources. • Changes in the supply of renewable resources related to species changes (e.g., agriculture, fishery, forestry)	• Continued and cumulative changes in marine and terrestrial ecosystems, including changes in renewable resource supply. • Continued impacts on accessibility of traditional food sources. • Fluctuations in energy supply and demand (e.g., fossil fuels, hydroelectric, renewables). • Continuation and intensification of all near-term impacts, except for successful early adapters.	• Interconnections between climate change impacts, adaptation measures and other socioecological changes at multiple levels, which are likely to create multiple and continually emerging risks. • Maximum uncertainty related to extreme climate change impacts. • Adaptive communities are likely still in transition. • Likely abandonment of non-adapted communities.

NEAR	MEDIUM	LONG-TERM
Livelihoods and economy (continued)		
• Increasing risk related to economic uncertainty. • Early adapters begin transitioning their economies at higher costs and with greater risk of failure. • Fluctuations in energy supply and demand (e.g., fossil fuels, hydroelectric, renewables).	• Potential loss of livelihoods and economies in many communities. • Fundamental changes to infrastructure, planning and economic transition in most communities; some may be abandoned due to loss of livelihoods.	• Possible migration with new forms of livelihood and economy.
Infrastructure		
• Transportation networks and services face increased risk of failure and disruption. • Impacts to transmission lines and energy grids. • Serious impacts on Northern infrastructure due to rapidly increasing average temperatures, precipitation and related changes. • Risk of injury from failure of physical infrastructure and stressed or degraded roads and traditional transportation routes. • Issues sustaining water and food security.	• Coastal communities are increasingly vulnerable to environmental emergencies, which disrupt activities necessary for daily life. • Loss and damage to critical and community infrastructure as a result of extreme weather events, inland and coastal flooding, sea level rise, permafrost thaw and forest fires. • Continuation and intensification of all near-term impacts.	• Continued disruptions to critical infrastructure, which are likely to result in adverse economic effects. • Increased energy prices. • Thawing permafrost and coastal erosion continue to affect residential and community infrastructure, particularly where planning and design have not considered changing climate conditions.

<table>
<tr><th>NEAR</th><th>MEDIUM</th><th>LONG-TERM</th></tr>
<tr><td colspan="3">Health and well-being</td></tr>
<tr><td>Increasing challenges with accessing healthy and culturally preferred food and water sources.
Risk of contamination in local food and water sources in remote polar regions due to increased levels of persistent organic pollutants and toxic metals in the natural environment.
Worsening of existing vectorborne, waterborne and foodborne diseases.
Development of new infectious diseases.
Risk of injury and death caused by extreme weather events and changing climate conditions.
Increasing mental health challenges connected to environmental uncertainties.</td><td>Increasing prevalence and severity of poor nutrition, obesity and diabetes related to changing access to certain foods.
Rising temperatures and more frequent extreme weather events may overwhelm fragile water treatment systems, affecting water security.
Changes to water levels, run-off, flow regimes and sediment, affecting drinking water availability and quality.
Increasing threats to safety and well-being in forest communities due to wildfire.
Continued intensification of mental health challenges.</td><td>The effectiveness of rural and remote health systems is increasingly challenged by reduced system capacity and the ongoing buildup of stresses related to climate change.</td></tr>
<tr><td colspan="3">Identity, culture and society</td></tr>
<tr><td>Shifts in cultural practices and identity associated with changes to the land.
Altered inter-generational transmission of Indigenous Knowledge.
Changes to the social fabric of rural and remote communities.</td><td>Loss of Indigenous Knowledge and disruptions to cultural continuity.
Erosion of land-based skills and knowledge.</td><td>Potential outmigration of youth and families, associated with increases in climate-related extreme weather events.
Climate-related stresses to the fabric of rural and remote communities.</td></tr>
</table>

NEAR	MEDIUM	LONG-TERM
Identity, culture and society (continued)		
• Increased storms, wind, sea level rise and coastal erosion, directly damaging sites of social and cultural importance. • Changing conditions leading to altered travel routes and disruptions in accessing places of cultural, social, spiritual and emotional significance.	• Continued losses to sense of place and identity resulting from irreversible losses, damage and destruction to landscapes and areas of cultural and social importance. • Continued alterations to place meanings and attachment, resulting from disruptions to connections to the land. • Storm damage associated with climate change can lead to enhanced social stress. • Climate-related stresses can heighten familial tensions and interpersonal conflict. • Climate-related stresses compound existing challenges to service provision and limited economic opportunities.	• Environmental crises may further entrench traditional gender roles, leading to less agency over adaptation strategies. • Continued intensification of challenges to cultural autonomy. • Continued losses to social capital. • Changing temperatures leading to potential extinction of local wildlife and plant species that are important aspects of natural heritage. • Unintended negative consequences of GHG emissions reduction and adaptation strategies, including adverse effects on economic opportunities and on the social fabric of communities.
Governance and institutions		
• Climate change impacts affecting infrastructure and service delivery, particularly during emergencies and related to the governance of land and natural resources.	• Climate change impacts continue to affect and require adaptation planning and policy.	• Continued strains on the ability of governance structures and institutions to respond to social, economic, cultural and environmental impacts related to climate change.

NEAR	MEDIUM	LONG-TERM
Governance and institutions (continued)		
• Difficulties in resolving disruptions to service delivery and in adaptation, due to disputes over jurisdictional responsibility and the need for continued improvements in communication and coordination. • Concern at local levels that senior levels of government are downloading additional responsibility to local institutions, which are already overstretched. • Challenges related to balancing the need to adapt to changing environmental conditions with meeting nationally-set GHG emissions reduction targets.	• Increases in average temperature, climate variability, drought and soil degradation result in high degrees of uncertainty for agricultural and other resource-dependent communities. • Increased uncertainty and challenges related to the ability to respond to environmental emergencies. Increased concern related to local capacity, without the provision of increased resources and support. • Continued challenges associated with top-down, inflexible governance structures, and in implementing intergovernmental and multi-stakeholder adaptation efforts.	• Incorporation of international perspectives into adaptation planning can further stress existing resources and human capacity.

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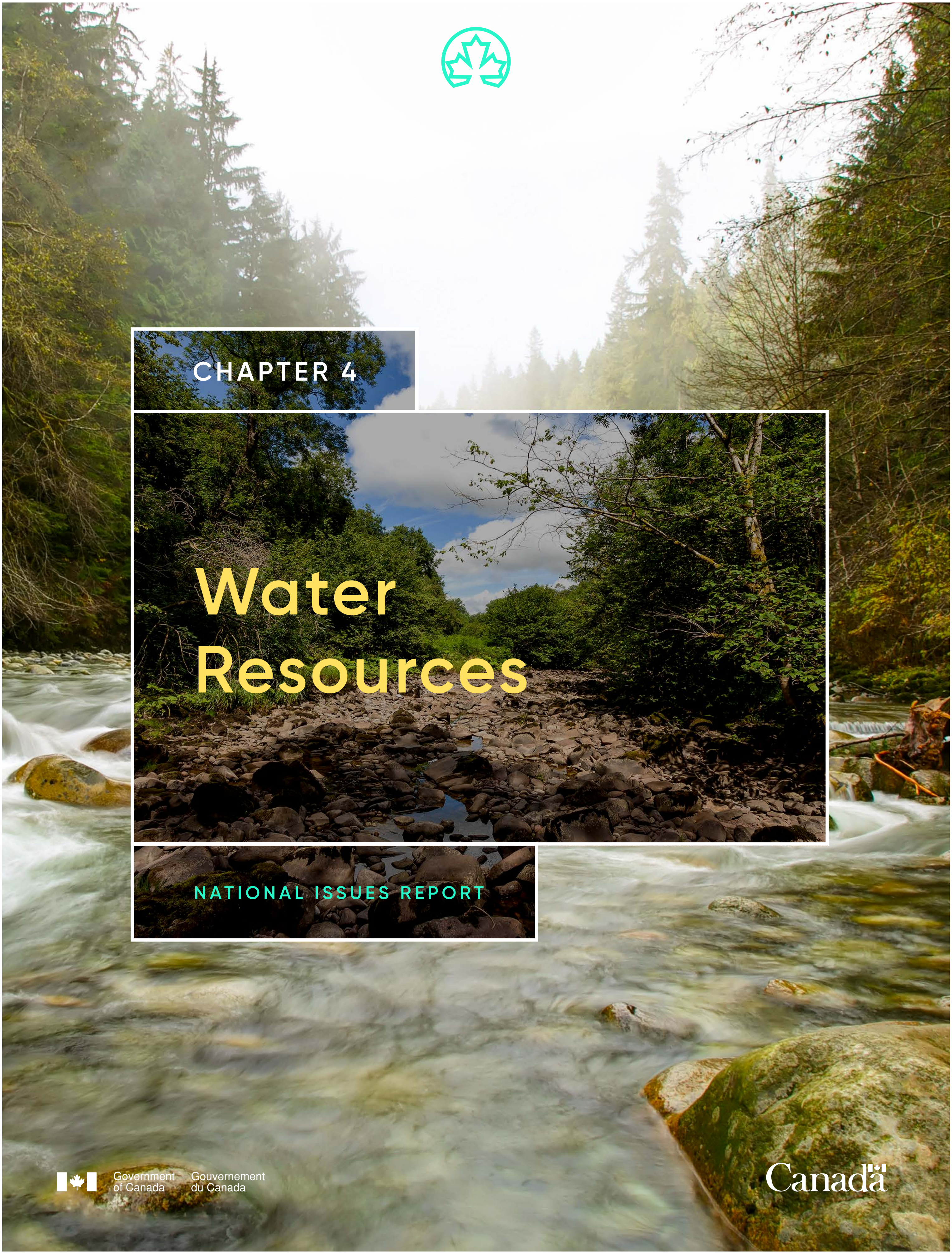

CHAPTER 4

Water Resources

NATIONAL ISSUES REPORT

Government of Canada / Gouvernement du Canada

Canada

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Key messages

Climate change creates risks for water resources (*see* Section 4.2)

Global climate change has already altered patterns of rainfall, snow, ice and permafrost melt, exacerbating existing water availability and quality issues, as well as changing the nature and timing of water-related natural hazards, such as floods and droughts.

Effective coordination across complex water systems enhances adaptation (*see* Section 4.3)

Canadian organizations and institutions are unevenly prepared to manage water-related risks associated with climate change. Partnerships and networks allow organizations at a variety of scales to access additional resources, share knowledge and risk, and enhance adaptive capacity. Transboundary and watershed organizations offer useful insights into effective coordination of water systems with diverse stakeholders that are dealing with high uncertainty.

Adaptation is advancing through innovation and adaptive management (*see* Section 4.4)

There are promising examples of coordination and innovation in the water sector across Canada. New approaches use scenarios to explore how decision-making strategies perform across a range of plausible futures, implement iterative processes for monitoring and adjusting actions, and engage stakeholders in social learning, laying the groundwork for innovation and adaptation.

It is vital to engage the public and build awareness about adaptation opportunities (*see* Section 4.5)

Successful adaptation requires public buy-in to the science of climate change and the need to implement adaptation policies. A majority of Canadians support policies to address water-related problems, but managing water resources ranks low on their list of salient problems after the economy, health care, and cost of living. Extreme events, including floods, droughts and episodes of poor water quality, can often bring the need for better water management to the forefront.

Water system vulnerability can be reduced through quality data and resilient design (*see* Section 4.6)

Reducing vulnerabilities in water systems involves identifying weak spots under current and future climate conditions, and providing access to high quality and locally relevant data. While the quality and resolution of data for monitoring change in uncertain environmental systems is variable, resilient design practices are emerging.

4.1 Introduction

Water is the vehicle that delivers many climate change impacts to society and the environment (IPCC, 2014). Water is a locally variable resource, and society's vulnerability to climate-related hazards, such as the impacts from flooding and drought, differ from one region to another. Vulnerability to hazards also stems from the ability of societal institutions to adequately prepare for and manage the new risks of climate change.

The availability of water is naturally limited, and water is not always in the right place at the right time, or of the right quality or quantity. Significant and varied water infrastructure and management systems have developed across Canada, designed primarily around the assumption that past natural variability is a reliable and robust indicator of future variability (Milly et al., 2008). With climate change, this assumption is no longer as valid, leaving practitioners and water managers often facing difficult and complex decisions (Simonovic, 2017).

Canada faces some special challenges in adapting its water systems to climate change. These include our large land mass, diverse geography, northern location and wide range of climate and hydrological regimes, coupled with a broad range of consumptive and non-consumptive uses that control the timing and supply of water resources (Statistics Canada, 2017). There are, for example, over 15,000 dams of various sizes administered by myriad jurisdictions, including federal, provincial and territorial governments, municipalities, irrigators, industries and utilities, for a wide range of purposes, including hydroelectricity, water supply, flood control, and mining and tailings management (Canadian Dam Association, 2019). The highly fragmented nature of water governance is also significant. While the constitutional responsibility for water resources management lies primarily with the provinces, the nature of the resource means that water resources are governed and managed by a complex system of stakeholders and partners, including governments at different levels, with participation from a variety of non-governmental organizations, local communities, and Indigenous and environmental organizations (Renzetti and Dupont, 2017). Effective coordination across these decision-making units enhances the capacity to share risk, learn from one another and seize opportunities to reduce vulnerability.

This chapter assesses the most up-to-date knowledge on climate and hydrological science and adaptation processes, and applies this knowledge to discuss the challenges, needs and opportunities that lie ahead for Canadian water resource managers and planners. The science presents a compelling case for action. However, equally important to assessing adaptation are the strengths and capacities of Canadian water institutions for changing business-as-usual systems of practice. In a large and diverse country like Canada, it is not surprising that the pace of adaptation is uneven, with more evidence of innovative local-scale responses, and less progress towards comprehensive national-scale strategies.

This chapter summarizes major adaptation efforts, while assessing the capacity of Canadian water institutions to respond to climate change and its associated uncertainties and complexities. It investigates the capacity of these institutions to plan for a future that may be substantially different from the past, to initiate a conversation about the kind of water future that people want and the policies needed to get there. It is still unclear whether governance systems, institutional practices and monitoring programs can change quickly enough to avert significant disruption and missed opportunities. Canada's institutional changes with respect to water resources are spotty and often bottom-up, but the case studies reviewed in this chapter demonstrate that local-level initiatives can serve as guides for more robust national action.

4.2 Climate change creates risks for water resources

Global climate change has already altered patterns of rainfall, snow, ice and permafrost melt, exacerbating existing water availability and quality issues, as well as changing the nature and timing of water-related natural hazards, such as floods and droughts.

Climate change impacts to the water cycle have already occurred, leading to damaged infrastructure, increased operating costs, disrupted operating seasons, and deteriorating water quality through excess nutrients and harmful algae blooms. Changes to overall water availability are projected to be more pronounced in the future, especially under high emissions scenarios. It is not always easy, however, to isolate climate change impacts from effects caused by human development, such as land use change. Human development can exacerbate or reduce climate-driven changes, introducing a considerable amount of uncertainty into the adaptation process.

4.2.1 Observed changes

Climate change has already affected Canada's cold-dominated water cycle, and has introduced risks to society and the environment (*see* Figure 4.1). Observed annual average temperature increases for Canada are about twice the global average, and more than three times the global average in Northern Canada (Zhang et al., 2019). *Canada's Changing Climate Report* (Bush and Lemmen, 2019) synthesizes the most recent scientific evidence of climate change impacts. Observed changes from the report that are relevant to water resources include:

- **Melting ice, thawing permafrost and shorter duration of snow cover**. Glaciers and ice fields are melting, thinning and retreating at unprecedented rates. Permafrost has warmed at many sites from the edge of the boreal forest to the tundra, and is disappearing along its southern boundaries. The portion of the year with snow cover and lake ice cover has decreased by 5% to 10% per decade since 1981 and seasonal snow accumulation has decreased in many regions (Derksen et al., 2019). These changes are particularly pronounced in Northern Canada, and present risks to the structural integrity of infrastructure (Lemmen et al., 2014) and can disrupt shipping routes and winter roads (Campbell et al., 2014; Lemmen et al., 2014). Over time, these changes may also introduce new mining and tourism opportunities in northern regions (Kovacs and Thistlethwaite, 2014; Lemmen et al., 2014), and are anticipated to increase the productivity of northern ecosystems as nutrients become more readily available (Orihel et al., 2017).
- **Increasing precipitation and a transition from snow to rain**. Precipitation has increased across all regions by an average of 20% since 1948. The greatest increases have occurred in Northern Canada and parts of Manitoba, Ontario, northern Quebec and Atlantic Canada. Precipitation is falling more often as rain rather than snow, especially in the spring and fall (Zhang et al., 2019). Increased precipitation and subsequent runoff have been linked with excess nutrients in water systems, increasing the incidence of harmful algae blooms (McCullough et al., 2012).

- **Changes in the timing of water availability**. The total volume of water flowing through a river basin[1] in an average year shows very little change, but significant shifts in timing have been observed (Bonsal et al., 2019). There is an increasing risk that less water may be available in hotter months for energy (Lemmen et al., 2014) and food production (Campbell et al., 2014), as early snowmelt contributes to lower summer flows (Bonsal et al., 2019). River and lake freeze-up now occurs later in the winter and over a shorter period of time, while ice break-up occurs earlier in the spring (Derksen et al., 2019). These shifts in timing can affect farming and industrial operations, and disrupt the natural patterns to which ecosystems have adapted (Islam et al., 2017; Campbell et al., 2014).
- **Changes in the nature of extreme events**. There are detectable changes in the nature of flood events in some areas, with more rain-on-snow events, rainfall-driven events and earlier spring flooding (Bonsal et al., 2019). For example, climate change played a role in the extreme rainfall events that contributed to the 2013 Calgary flood (Teufel et al., 2017), the 2014 Assiniboine flood (Szeto et al., 2015), and the 2017 Ottawa floods (Teufel et al., 2019). Canadian municipal planners rank extreme storm events and flooding as the two most frequently experienced climate change impacts (McMillan et al., 2019), and these events can increase contaminant loads in water systems, degrading water quality (Gooré Bi et al., 2015; Jalliffier-Verne et al., 2015). While costly, observed changes in droughts to date represent yearly variations from the normal, rather than the product of long-term trends related to climate change (Bonsal et al., 2019).

Thus far, these observed changes have resulted in varied impacts to average annual river flows and lake levels (Bonsal et al., 2019) due to the tremendous amount of variation in natural systems and increased evaporation (Bonsal et al. 2019; Bush et al., 2019). There remains considerable uncertainty, especially in terms of predicting the timing, magnitude and direction of changes in precipitation. For example, while there do not appear to be detectable trends in short-duration extreme precipitation events in Canada (Zhang et al., 2019), other studies find increasing trends in extreme precipitation events over large portions of North America (Kirchmeier-Young and Shang, 2020; Paplexiou and Montanari, 2019). Unfortunately there is no consensus in the literature, largely because rainfall is extremely difficult to simulate, especially summertime convection. Ultimately, reported changes are really a patchwork of different changes across Canada that are heavily influenced by such things as latitude, altitude and proximity to lakes, which makes a pan-Canadian assessment very local by necessity. Additionally, human management decisions related to land-use, water management and changing socioeconomic conditions (Bonsal et al., 2019; Statistics Canada, 2017), can reduce or exacerbate climate change-driven processes, and can impact the water cycle on the same order of magnitude as hydroclimatic changes (Döll et al., 2015). For example, while some climate change processes have been linked to deterioration of water quality in Canada, a number of studies have also found strong links to land-use intensification with agricultural production and urban development (Weiss et al., 2018; El-Khoury et al., 2015; Gooré Bi et al., 2015; Jalliffier-Verne et al., 2015; Taranu et al., 2015). These human management elements introduce considerable uncertainties into future projections and complexities into future decision making (*see* Case Story 4.1).

1 A river basin refers to the area of land that drains into a river, including its contributing tributaries such as streams and creeks. Watersheds represent smaller sub units of a river basin that capture precipitation and drains it towards a water source.

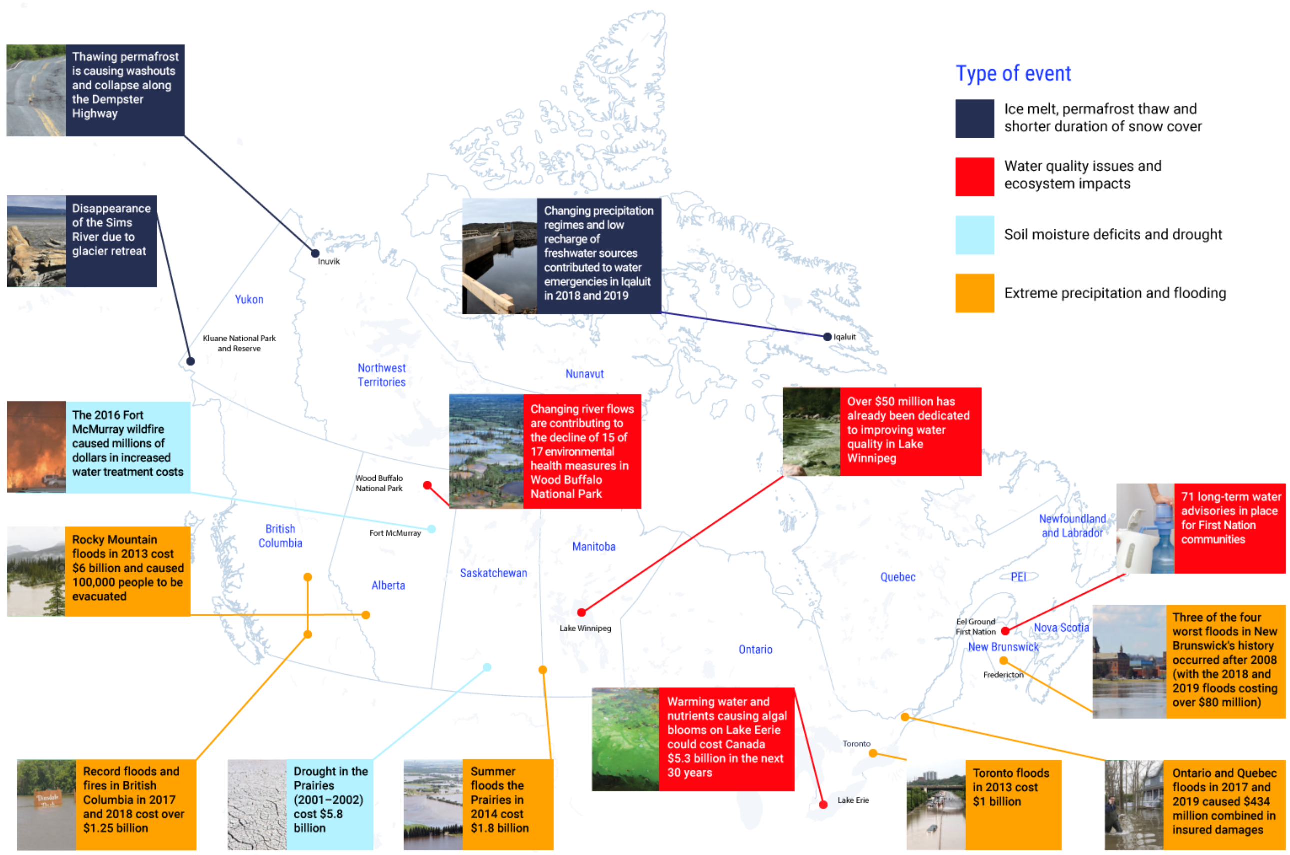

Figure 4.1: Major recent events and trends in Canada related to water resources that have had significant impacts to communities and the economy. Source: Adapted from Government of Canada, 2020a, b; Government of New Brunswick, 2019; Insurance Bureau of Canada, 2019a; McKay, 2019; Ormiston and Sheldon, 2019; Poitras, 2019; Smith et al., 2019; Wang and Strong, 2019; Abbott and Chapman, 2018; Environment and Climate Change Canada, 2018; Lindsay, 2018; Weber, 2018; Bakaic, 2017; Insurance Bureau of Canada, 2019a, 2017; Maclean, 2017; O'Neill and Burn, 2017; Phillips, 2017; Thurton, 2017; Weikle, 2017; Sills et al., 2016; Wheaton et al., 2008; Public Safety Canada, n.d.

Case Story 4.1: Extreme water level variability on the Great Lakes

The Great Lakes are the largest surface freshwater system on Earth and serve the diverse needs of 30 million people. Water levels across the Great Lakes were very high throughout 2019 and have continued to be high in 2020, approaching or exceeding seasonal or all-time record-high water levels at various times throughout the year. During 2019, Lake Superior, Lake Saint Clair, Lake Erie and Lake Ontario all met or exceeded all-time record high levels for the period of record of 1918–2018. In the case of Lake Ontario, the new record-high level set in 2019 exceeded the previous record-high level set only two years prior in 2017. Lake Michigan–Huron, which came very close to record highs in the summer of 2019, remained high through the fall, and was above seasonal records in the winter and spring of 2020. High water levels have caused flooding and erosion along the shorelines of all the Great Lakes, with enhanced local impacts during storm events generating wind-driven wave action (*see* Figure 4.2; Toronto and Region Conservation Authority, 2019; Great Lakes–St. Lawrence River Adaptive Management Committee, 2018). While it is outside of the Great Lakes basin, the Ottawa River experienced its largest spring flows on record in 2019, surpassing its previous record reached just two years before, in 2017 (Ottawa River Regulation Planning Board, 2019), which caused flooding throughout the Ottawa River basin and downstream on the St. Lawrence River. Communities battled emergency conditions, and water regulators attempted to balance upstream and downstream flooding conditions (Ottawa River Regulation Planning Board, 2019; Great Lakes–St. Lawrence River Adaptive Management Committee, 2018; International Lake Ontario–St. Lawrence River Board, 2018). Only six short years earlier, shoreline communities on the Upper Great Lakes had been adjusting to a fifteen-year period of very low water levels, with Lake Michigan–Huron at an all-time record low level in the winter of 2013 (Gronewold et al., 2016).

Figure 4.2: Record high water levels and flooding on a dock near Saint Catharines, ON (left), and a walkway near Ontario Place in Toronto, ON (right). Photos courtesy of Environment and Climate Change Canada.

While water level fluctuations are normal on the Great Lakes, these extreme shifts between record low and high water levels fit the pattern of what would be expected under a changing climate. Projections for the future are not simply that water levels in the Great Lakes will trend up or down, but rather that they will experience more frequent periods of very high or very low levels (Gronewold and Rood, 2019; Mailhot et al., 2019; Music et al., 2015; Notaro et al., 2015). Extreme water levels have occurred in the recorded past (1918–2018) (Canadian Hydrographic Service, 2019; Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, 2019), and therefore it is difficult to determine whether the record-breaking conditions in 2017 and 2019 are extraordinarily rare events for the climate in this region, or moderately rare events in a climate that is changing (Great Lakes–St. Lawrence River Adaptive Management Committee, 2018). An event attribution study by Teufel et al. (2019) shows that events such as the heavy April 2017 precipitation accumulation over the Ottawa River basin are between two and three times more likely to occur in the present-day climate than they were in the pre-industrial climate, as the current warmer atmosphere holds more moisture. The record high and low water levels across the Great Lakes are a clear reminder that these types of extreme conditions are not only plausible, but are indeed occurring, with growing evidence of linkages to climate change. Planning is difficult in this context, as shoreline communities struggle to adjust and adapt to uncertain future conditions (Gronewold and Rood, 2019; McNeil, 2019).

Adaptation planning must manage uncertainty, rather than try to avoid it (Kwakkel et al., 2016). Emerging insights from adaptive management theory and practice suggest that building resilience—the ability to withstand a wide range of scenarios—into both human and ecological systems is an effective way to cope with environmental change characterized by future uncertainty (Pahl-Wostl, 2008; Panel on Adaptive Management for Resource Stewardship, 2004). Adaptive management techniques allow planners and practitioners to move forward with decisions and actions that meet current needs and conditions, and then to respond with modifications if conditions change in an unanticipated manner (Land Trust Alliance, 2019; Wood et al., 2017). The International Joint Commission has adopted such an adaptive management approach as a means of dealing with future uncertainty on the Great Lakes (*see* Case Story 4.5 and Section 4.4.5 for examples in the Great Lakes Region).

4.2.2 Climate trends and projections

Combined changes in precipitation phase (e.g., rain or snow), earlier snowmelt, ice cover retreat and decreasing glacier mass affect Canadian river flows and lake levels. Future trends identified in *Canada's Changing Climate Report* (Bush and Lemmen, 2019) and other studies, include:

- **Less water availability in southern basins, particularly in the summer.** Precipitation will continue to increase in the short term for all seasons, but summer rainfall in southern Canada is projected to decrease in a high emissions scenario near the end of the century (Zhang et al., 2019). Along with increasing evaporation rates, early snowmelt and less ice, this trend is expected to contribute to reduced annual flows in southern interior basins and southern lake levels (Bonsal et al., 2019), potentially initiating social and ecological conflict over increasingly scarce water resources in some basins (Clark et al., 2017).
- **Increased frequency and intensity of water-related extremes.** Some conditions that increase the potential for flooding, such as extreme rainfall events, are projected to be more common in the future, escalating the potential for rain-generated local flooding, particularly in urban areas (Zhang et al., 2019). Extreme precipitation events can lead to the loss of human life and property destruction (Simonovic, 2017), and can affect mining operations, energy transmission and tourism infrastructure (Kovacs and Thistlethwaite, 2014; Lemmen et al., 2014), as well as increase soil erosion and nutrient runoff, degrading water quality (Campbell et al., 2014; Crossman et al., 2013). Extreme summer dry periods are expected to increase in frequency and will contribute to soil moisture deficits leading to drought, particularly across the southern Prairies and in the interior of British Columbia (Bonsal et al., 2019; Zhang et al., 2019).

- **Reduced water quality and more harmful algae blooms.** There is significant potential for climate change to exacerbate current water quality issues (Liu et al., 2019; Gooré Bi et al., 2015; Jalliffier-Verne et al., 2015). In particular, it is anticipated that warmer temperatures will contribute to additional occurrences of harmful algae in the future, particularly where nutrient concentrations are already elevated (Orihel et al., 2017; Paterson et al., 2017).

Climate change influences on the water cycle are already impacting Canadian food, energy and natural resource sectors, communities, and the natural environment. For example, property and casualty insurance payouts from extreme weather events have more than doubled every five to ten years since the 1980s, and the Insurance Bureau of Canada estimates that for every dollar of insured loss, home and business owners and governments spend three to four dollars for uninsured losses (Moudrak et al., 2018). Since 2009, insured losses from catastrophic severe weather events in Canada, such as flooding, have averaged $1.4 billion per year, compared to an average of $400 million per year prior to this (Insurance Bureau of Canada, 2019b).

The current reality for water practitioners in every part of Canada is that design and operational protocols for water resources management are almost exclusively based on a historical understanding of the resource. However, as we move into the Anthropocene (i.e., the era in which human activity has been the dominant influence on climate and the environment), indications are that the future will no longer resemble the past. Adapting to new changes is made more complex by the interaction of climate change with human development and by rapidly changing socioeconomic conditions. While uncertainties create challenges for adaptation, they should not be an impediment to action. Instead, they can serve as a call to address uncertainty, and to develop more robust management systems that can cope with variability. The remainder of this chapter provides a national perspective on adaptation efforts in the water resources sector, with a focus on how governments, communities and civil societies are adapting to complex and uncertain change.

4.3 Effective coordination across complex water systems enhances adaptation

Canadian organizations and institutions are unevenly prepared to manage water-related risks associated with climate change. Partnerships and networks allow organizations at a variety of scales to access additional resources, share knowledge and risk, and enhance adaptive capacity. Transboundary and watershed organizations offer useful insights into effective coordination of water systems with diverse stakeholders that are dealing with high uncertainty.

Canadian governance of water resources involves primarily the provincial and municipal/regional governments with involvement from federal and Indigenous governments, along with civic societal organizations such as watershed groups, environmental organizations, philanthropic foundations and scientific and research groups. Capacity challenges often occur in rural, northern and Indigenous communities. Coordination, sharing agreements and partnerships enhance the capacity to self-organize, share risk, and incorporate multiple *sources of knowledge (e.g., scientific, Indigenous, social, practitioner). Networks enhance institutional capacity to address the uncertainty posed by climate change, and they support local organizations, help to share risk, and incorporate new forms of knowledge. Watershed organizations, such as Ontario's Conservation Authorities, and transboundary organizations, such as the International Joint Commission, exemplify the benefits and challenges of coordination around shared water resources.*

4.3.1 Introduction

A common climate change adaptation strategy involves coordination across organizations and institutions. An organization is a group of people devoted to a particular purpose, such as research or a business aim, while an institution is a type of formal organization, and also refers to systems of practices, norms and formal laws or policies (Hulbert and Gupta, 2017). For example, the World Meteorological Organization (WMO) is an organization providing world leadership and expertise in international cooperation in the delivery and use of high-quality, authoritative weather, climate, hydrological and related environmental services by its members. The WMO facilitates an international greater good, while member countries maintain sovereignty and provide funding to the WMO to maintain this oversight role. The Global Institute for Water Security at the University of Saskatchewan and the Water Institute at the University of Waterloo are examples of institutions that function similarly to an organization. The broader definition of water institutions also refers to formal water laws and policies (e.g., the Water Sustainability Act in British Columbia), water governance arrangements (e.g., Conservation Districts in Ontario), market-based mechanisms (e.g., Alberta's water market), public opinions about water and climate change, and attitudes towards public and private ownership, among other things. Organizations are governed by rules and regulations, whereas institutions are governed by customs and values. Canadian water institutions have deeply engrained patterns of how we manage water, and they are in the process of adapting to climate-related water risks through new institutional arrangements, enhanced coordination, risk sharing and capacity building (Global Water Futures, 2020). Coordination allows institutions to respond more quickly and effectively to the challenges of an uncertain climate by defining clear roles, fostering information sharing and mobilizing additional resources (Hurlbert and Diaz, 2013; Bakker and Cook, 2011). Risk-sharing tools distribute capacity to prepare for climate change impacts (Thistlethwaite and Henstra, 2017).

In Canada, the constitutional division of power between federal, provincial, territorial and Indigenous governments, and the role of municipal and regional organizations means that adaptation in the water sector often occurs at a variety of scales (Global Water Futures, 2020; Renzetti and Dupont, 2017; Bakker and Cook, 2011; Sandford et al., 2011; Simms and de Loë, 2010). This decentralized context for governance can lead to a mix of outcomes for adaptation in the water sector. On one hand, the fragmentation of governance across multiple authorities can result in inefficiencies and redundancies (Bakker and Cook, 2011) that contribute to unsustainable water use (Renzetti and Dupont, 2017), delayed policy development (Mitchell, 2017), and uneven adaptive capacity across stakeholder groups (Hurlbert and Diaz, 2013). In other circumstances, decentralized governance is inclusive of many groups and can produce outcomes that are responsive to local needs (Bakker and Cook, 2011). Often, intermediary groups such as watershed organizations (*see* Case Story 4.2) and transboundary water organizations (*see* Case Story 4.3) can play an important coordination role across various stakeholder groups (Clancy, 2014). Municipalities, Indigenous communities and environmental organizations are also becoming more commonly included in water governance and adaptation activities, in part due to the fact that the federal role in water governance has declined over several decades (*see* Box 4.1; Renzetti and Dupont, 2017; Hurlbert et al., 2015; Bakker and Cook, 2011; Simms and de Loë, 2010; Hill et al., 2009; Ivey et al., 2004). These diverse sets of new actors often have novel ideas about water management and adaptation to risk that can transform existing institutions (Clancy, 2014).

Ideally, networks and partnerships between governance authorities and stakeholders can play a significant role in strengthening adaptation of the Canadian water sector to climate change (Bauer and Steurer, 2014). Effective coordination implies that programs are necessary, efficient, consistent and comprehensive (de Loë, 2017). Improved water governance arrangements are important for clarifying roles and coordinating policies across all orders of government (Bakker and Cook, 2011; de Loë, 2009), and in sectors beyond water, such as energy and agriculture (de Loë, 2017; Gober, 2013).

Box 4.1: Flood management in Canada

Floods are among the most costly natural disasters in Canada (Insurance Bureau of Canada, 2019b; Public Safety Canada, 2011). Seventy-five percent of annual weather event expenditures under the Federal Disaster Financial Assistance Arrangement program are flood-related (Office of the Parliamentary Budget Officer, 2016).

Historically, the federal government has played a substantial coordinating role in reducing flood risk. In 1970, Canada passed the Canada Water Act to design an enhanced national and comprehensive approach to water management (Watt, 1995). The federal–provincial/territorial Flood Damage Reduction Program (FDRP) was introduced in 1976 to identify flood hazards, map floodplains, discourage flood-vulnerable development, and encourage effective land use in flood-vulnerable areas. This initiative was a significant shift away from reactive, ad hoc flood policy and towards a proactive approach and preventative philosophy. Between 1976 and 1999, the FDRP was the main mechanism coordinating national action on flood risk reduction, including facilitating cost sharing between governments, supporting the development of flood risk maps, and assisting in the implementation of structural and non-structural methods for flood control (Scott et al., 2017; Thistlethwaite and Henstra, 2017; Watt, 1995). Ultimately, the program designated 320 flood-risk areas covering more than 900 urban communities (Natural Resources Canada, 2018).

Since the FDRP was discontinued in 1999, flood management has become highly fragmented and currently reflects uneven adaptive capacity across the country. A 2014 review of flood risk approaches across Canada found that approximately half of existing flood mapping was completed after the discontinuation of the FDRP (MMM Group, 2014), with 59% of these instances being in Ontario, 21% in Quebec, 10% in British Columbia, and the remaining 10% distributed across the rest of the country. A more recent study found that, while many Canadian municipalities have some sort of flood map, most of these maps are of poor quality and are ill-suited for communicating flood risk to the public (Henstra et al., 2019a). Institutional fragmentation appears to be a particular challenge to building resiliency. In interviews with city officials in 15 major Canadian cities, Feltmate and Moudrak (2015) found that cities have made minimal flood preparations in areas where they have limited or shared jurisdiction, such as food, electricity and petroleum supply. Similarly, Morrison et al.

(2018) interviewed experts in the Canadian Prairie provinces, and identified the lack of coordination between the various agencies responsible for flood risk management as a challenge to building resiliency, resulting in a duplication of efforts, siloed expertise and gaps in responsibilities.

The Federal Flood Mapping Guideline Series provides governments and organizations with resources, technical guidance and support for conducting risk assessments and floodplain mapping. The first document in the series, released in 2018, will facilitate a common national best practice and will increase the sharing and use of flood hazard information (Natural Resources Canada, 2018). Also, Natural Resources Canada and Public Safety Canada released the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation in 2019, which provides technical guidance to support the development of flood hazard maps in a Canadian jurisdiction, including on different types of flooding and how to consider climate change in the flood mapping process. In recent years, all levels of governments have been investing to update flood maps across Canada, which are outdated and lack consistent standards. Although there are examples of communities and jurisdictions incorporating climate change into flood mapping (Natural Resources Canada and Public Safety Canada, 2018), there is a need for further overarching guidance on how to address the potential impacts of climate change on floodplain mapping in Canada.

4.3.2 Transboundary and watershed organizations

Canadian water organizations with mandates spanning jurisdictional boundaries and involving a variety of stakeholders have built cooperative institutional structures to promote shared understanding, trust and capacity for addressing complex and contentious water management challenges in a coordinated fashion. These groups can effectively link decision-making processes and priorities across scales and regions, and they are well-positioned to continue to drive participatory and adaptive water governance (Rouillard and Spray, 2017; Mguni, 2015; Cook et al., 2013). Transboundary organizations are expected to be particularly important in addressing potential interregional or international water conflicts that may be exacerbated by climate change (De Stefano et al., 2012). However, the ability of these organizations to continue to collaborate and respond to increasing risks posed by climate change has not been sufficiently studied (Akamani and Wilson, 2011).

A variety of regional organizations with water management mandates exist in Canada, many of them based on watershed boundaries rather than political boundaries. Examples include Alberta's Watershed Planning and Advisory Councils, Saskatchewan's Watershed Associations, Manitoba's Watershed Districts, Quebec's *organismes de bassins versants*, watershed groups in Prince Edward Island, New Brunswick and Nova Scotia, and water boards in the Yukon, Northwest Territories and Nunavut. Some of these groups have legislative authority, such as Ontario's Conservation Authorities (*see* Case Story 4.2), others are financially supported by provincial government programming, such as in Prince Edward Island and New Brunswick, while others exist as non-profit organizations or citizen-run groups, such as the Fraser Basin Council in British Columbia (Scott et al., 2017; Canadian Council of Ministers of the Environment, 2016). These groups have played key roles in coordinating action on adaptation planning across the country (Oulahen et al., 2018; Mitchell et al., 2014; Ontario Centre for Climate Impacts and Adaptation Resources, 2011; Sandford et al., 2011). The watershed approach to governance can link land use and water management activities, and enable collaboration between a variety of upstream and downstream stakeholders (Mguni, 2015).

Case Story 4.2: Ontario Conservation Authorities and climate change adaptation in the Lake Simcoe Watershed

Ontario Conservation Authorities are 36 watershed-based partnerships between municipalities and the Province with legislative authority "to undertake watershed-based programs to protect people and property from flooding, and other natural hazards, and to conserve natural resources for economic, social and environmental benefits" (Conservation Ontario, 2020; Scott et al., 2017). Conservation Authorities were originally formed to foster greater cooperation and collaboration among the various groups involved in water management (Mitchell et al., 2014), and now play a key role in building resilience to water-related risks (Ontario Centre for Climate Impacts and Adaptation Resources, 2011). For instance, the Lake Simcoe Region Conservation Authority (LSRCA; *see* Figure 4.3) was one of the partners involved in a multi-partner pilot project to develop a climate change adaptation strategy for the Lake Simcoe Watershed in Ontario. This watershed encompasses about 330,000 ha, is home to approximately 350,000 people, and generates over $200 million annually for the local economy, primarily through agriculture and recreation (Lake Simcoe Region Conservation Authority, 2016; Ontario Centre for Climate Impacts and Adaptation Resources, 2012). The climate change adaptation plan was made possible through a number of enabling legislative and policy mechanisms, including the Lake Simcoe Protection Act (the first legislation in Canada to focus on a single watershed), the Lake Simcoe Protection Plan (the first plan in Ontario to integrate climate change considerations) and Ontario's Climate Ready: Adaptation Strategy and Action Plan (2011–2014) (Lemieux et al., 2014). With other partners, the LSRCA identified current and future climate change vulnerabilities, such as the drying of wetlands and spread of aquatic invasive species, using future scenarios of climate and non-climate stressors. The team solicited adaptation ideas and prioritized them with an expert panel, organizing them into themes of engaging people (e.g., ensuring community engagement and interagency cooperation and coordination), reducing threats (e.g., encouraging and supporting water conservation), enhancing adaptive capacity (e.g., determining how well plans account for and protect important natural assets) and improving knowledge (e.g., instituting standardized monitoring of species at risk) (Lemieux et al., 2014).

Figure 4.3: Map of the Lake Simcoe Watershed in Ontario. Source: Lake Simcoe Region Conservation Authority, 2016

The LRSCA is currently engaged in updating and improving the adaptation plan for the Lake Simcoe Watershed. In the meantime, it is building resilience to climate change impacts primarily through promoting low-impact development projects such as natural infrastructure (*see* Section 4.6.3), and through implementing a new Phosphorus Offsetting Policy. Excess phosphorus from land-use activities and their consequences, such as agriculture and urban runoff, is a major threat to the current health of Lake Simcoe, degrading water quality and leading to excessive growth of aquatic plants and algae (Weiss et al., 2018; Lake Simcoe Region Conservation Authority, 2017). Climate change is exacerbating this process by contributing to more extreme rainfall events and by changing the timing of seasonal flows, affecting runoff volumes into the lake (Lake Simcoe Region Conservation Authority, 2013). The LSRCA has been working with partners to improve urban storm water management, and has introduced an offsetting policy that requires new development to control 100% of the phosphorus leaving their property (Lake Simcoe Region Conservation Authority, 2019).

There are also a variety of transboundary water organizations in Canada. The most prominent of these is the International Joint Commission (IJC), established under the Boundary Waters Treaty of 1909. The IJC is a binational institution for the resolution of water disputes and cooperation on water policy priorities across the U.S.–Canada border. There are a total of 13 transboundary water systems governed by the 1909 Boundary Waters Treaty, including the Osoyoos, Kootenay and Columbia rivers, the Saint Mary and Milk rivers, the Souris River, the Red River, the Rainy River and Lake of the Woods, the Great Lakes–St. Lawrence River (*see* Case Story 4.3), Lake Champlain and the Richelieu River, and the Saint Croix River. Many of these transboundary systems have IJC boards, studies and committees dedicated to binational water management issues. Other transboundary organizations and agreements address interjurisdictional drainage basins, such as the Prairie Provinces Water Board (the 1969 Master Agreement on Apportionment), the Ottawa River Regulation Planning Board (1983 Agreement Respecting Ottawa River Basin Regulation) and the Mackenzie River Basin Board (the Mackenzie River Basin Transboundary Waters Master Agreement).

Case Story 4.3: The International Joint Commission and the Great Lakes Region

The role of the International Joint Commission (IJC) in the Great Lakes Region demonstrates successful coordination of policy design and implementation in a decentralized context. The Great Lakes Region is home to one of the largest freshwater basins on earth, serving more than 30 million people. Regional water governance is characterized by a complex set of policies and arrangements involving two countries, more than 75 First Nations communities along the coasts, eight states and two provinces, numerous municipalities, and a variety of users and stakeholders with different roles and concerns. While outstanding policy issues remain, the United States and Canada have slowed substantial ecological damage in the basin (Renzetti and Dupont, 2017; Carmichael and Boyer, 2016), with the IJC playing a key role in coordinating engagement across stakeholder groups, and completing technical and policy work around issues such as regulating shared water uses and water quality (Johns, 2017). Notable activities and accomplishments recognized internationally (United Nations, 2015) include the following:

- Large transboundary integrated assessments, such as the Lake Ontario–St. Lawrence River Study (1990–2005) and the International Upper Great Lakes Study (2007–2012). These studies resulted in flexible management plans and operating rules to respond to climate variability and uncertainty (*see* Case Story 4.5; International Upper Great Lakes Study Board, 2012, 2009; Stakhiv et al., 2006).
- The Great Lakes Water Quality Agreement to maintain the chemical, physical and biological integrity of the Great Lakes Basin ecosystem. The Great Lakes Water Quality Protocol of 2012, enacted under the Great Lakes Water Quality Agreement, is one of the only transboundary coordinating instruments in the world to explicitly address the impacts of climate change on water quality (United Nations, 2015; Government of Canada and Government of the United States of America, 2012).
- A Climate Change Framework (2018) providing guidance for transboundary IJC boards for addressing climate change in policy and operations to maintain the resilience of Canada–U.S. water systems (IJC, 2018).

Some of the success of the IJC can be credited to its multi-disciplinary teams, meaningful engagement with stakeholders, and willingness to incorporate new ways of learning and information sharing (Straith et al., 2014).

While transboundary organizations are strong coordinating forces in the Canadian water sector, their mandates and water sharing agreements rarely take into account climate change. Vulnerabilities such as the absence of flow apportionment agreements or drought provisions in periods of low or variable flow have been noted in the Columbia River Basin (Garrick, 2017) and the Red River Basin (de Loë, 2009). The Prairie Provinces Water Board, which oversees water sharing among Alberta, Saskatchewan and Manitoba, has explicitly considered climate change and drought as key stressors in technical work, but finds it more difficult to take into account changing and uncertain socioeconomic factors, such as voluntary water sharing (Global Water Futures, 2020). The IJC considers climate change in multiple products, including in a framework to guide climate change considerations across transboundary boards (IJC, 2018), in the climate change impacts annex in the Great Lakes Water Quality Agreement (United Nations, 2015) and in the creation of the Great Lakes–St. Lawrence River Adaptive Management Committee (IJC, 2015). An adaptive management approach to transboundary management can be an effective way to respond to changing circumstances and may include the following: periodic reviews; limited terms; special provisions for meeting environmental water needs; mechanisms for dealing with extreme circumstances, such as floods and droughts; information sharing; and the creation of organizations that are empowered by the parties to make adjustments in response to changing circumstances (*see* Section 4.4; de Loë, 2009).

While transboundary water organizations strengthen Canada's ability to adapt, the existence of these organizations alone is not sufficient. A lack of leadership in coordinating action and a failure to sustain policy attention have been noted as issues impeding progress in both the Great Lakes Region (Johns, 2017) and the Mackenzie River Basin (Morris and de Loë, 2016).

4.3.3 Adaptive capacity and the changing nature of water governance

Access to adequate technical, human, social and financial capital is critical to adaptive capacity in the water sector (Hurlbert and Diaz, 2013; Ontario Centre for Climate Impacts and Adaptation Resources, 2011). Practitioners in the field point to declining technical skills and resources (ICF, 2018; Hamlet, 2011; Patino, 2010), employee turnover and burnout (Global Water Futures, 2020; Moncrieff-Gould et al., 2018; Straith et al., 2014), and a lack of stable funding (Moncrieff-Gould et al., 2018) as challenges to adaptation in the water sector (McMillan et al., 2019; Oulahen et al., 2018). Contextual, place-based knowledge, networks, and a wide range of interdisciplinary skills are all assets in enhancing a community's ability to respond, survive and adapt to climate-related situations such as extreme events (Global Water Futures, 2020; Straith et al., 2014).

Capacity challenges are often more evident in communities and organizations that are most vulnerable to water-related risks of climate change, including in rural, northern and Indigenous communities (Global Water Futures, 2020; Archer et al., 2017; Ecology North, 2017; Clancy, 2014; Willox et al., 2013; Ford and Pearce, 2010; Wall and Marzall, 2006; Ivey et al., 2004). As a result, such organizations and communities are unevenly prepared for the water-related impacts of climate change. Financial resource constraints are particularly challenging for non-governmental groups and local communities. Many non-governmental water organizations are volunteer-based, or lack streamlined, stable core-funding opportunities to engage in effective networking with each other and with the public about water-related issues (Global Water Futures, 2020; Mitchell et al., 2014; Telfer and Droitsch, 2011). Similarly, those in rural and Indigenous communities are more susceptible to disruptions to reliable income sources, such as flooding on cropland or culturally significant foraging areas (Fletcher and Knuttila, 2018; Lemmen et al., 2014; Wandel et al., 2010; Wall and Marzell, 2006). However, communities that have recently experienced water-related natural hazards, such as flooding or drought, are generally more adaptive than those lacking this experience (Di Baldassarre et al., 2015). For example, the long history of extreme climate variability experienced by rural communities in the Canadian Prairies has generally increased adaptive capacity across the region, through adaptations such as the expansion of irrigation infrastructure and crop diversification (*see* Prairie Provinces chapter; Kulshreshtha et al., 2016; Hurlbert and Diaz, 2013).

Significant progress has been made towards climate change adaptation in North America at the municipal level (Canadian Water Network, 2019; Oulahen et al., 2018). Municipalities, however, often lack capacity to raise the revenue necessary to maintain and upgrade infrastructure, despite being responsible for 60% of public infrastructure across Canada (Global Water Futures, 2020; Moncrieff-Gould et al., 2018; Thistlethwaite and Henstra, 2017; Miller, 2015). While about half of municipalities have undertaken a risk assessment of their water-related assets, fewer than 20% have formally introduced climate change adaptation strategies (Canadian Infrastructure Report Card, 2016). Others have not carried out any assessment whatsoever of their community's vulnerability to specific climate change impacts (McMillan et al., 2019). As such, communities are unevenly prepared to handle water-related extremes like floods (Feltmate and Moudrak, 2015).

Indigenous communities have displayed remarkable resilience in the face of considerable and rapid change over the past century. In northern Canada, where the temperature is warming three times faster than the global average (Bush and Lemmen, 2019), the impacts of climate change have been felt acutely by Inuit communities in changing patterns of sea ice, thawing permafrost and the loss of snow and ice cover (Inuit Tapiriit Kanatami, 2019). Communities have already had to modify behaviour to cope with these rapid changes, including hunting in boats on open water rather than from ice floes, using all-terrain vehicles instead of snowmobiles, and utilizing sea routes rather than inland routes damaged by permafrost thaw (Berkes and Armitage, 2010). High levels of adaptive capacity exist in Inuit communities, via knowledge systems that incorporate change and uncertainty, and through adaptive practices, such as diversifying the timing and type of land-based activities (Cameron et al., 2015; Ford et al., 2015; Berkes and Armitage, 2010). However, adaptive capacity may not be able to keep pace with the rapid rate of environmental change in the north. Furthermore, many traditional Inuit strategies to manage change continue to be undermined by colonial processes that have severely affected Indigenous populations in the Arctic (Ford et al., 2017; Ford et al., 2015). Indigenous communities elsewhere in Canada face similar challenges, including the effects of industrial pollution, the downstream impacts of hydropower dam operations, and on-going socioeconomic issues, such as high costs of living and limited employment opportunities, many of which stem from the continuing legacy of systemic racism and colonial policies (Global Water Futures, 2020; Archer et al., 2017; Thompson, 2015; Castleden and Skinner, 2014; Clancy, 2014; Magzul and Rojas, 2006). These compounding factors inhibit the ability of these communities to consider and undertake water resource adaptation planning. Competing priorities and limited human and technical capacity mean that communities are not always able to take advantage of financial resources to promote and implement adaptation plans, even when such resources are available (Ecology North, 2017; Ford and Pearce, 2010).

To increase adaptive capacity, organizations across Canada are creating partnerships to address the water-related risks of climate change. Partnerships exist across different scales (national, regional and local) and types of organizations (government, industry, academia, civil society), and facilitate information sharing (Straith et al., 2014), trust building and cooperation (Moore et al., 2014; Patino, 2010), as well as adding technical and human resources (Global Water Futures, 2020; Dale et al., 2019; Hamlet, 2011; Cohen et al., 2006).

National and international institutions also support local self-organization and social networking around water issues. For example, a key facilitator of adaptation at the municipal level is the International Council for Local Environmental Initiatives (ICLEI), a network of local governments and staff that provide technical capacity and networking opportunities. Working with the Federation of Canadian Municipalities, ICLEI is a key driver of municipal greenhouse gas (GHG) emissions reduction and climate change adaptation in Canada (Dale et al., 2019; Guyadeen et al., 2018). While many provinces have released guidelines or funding programs supporting adaptation at the local level, Ontario was the first province to enact regulations requiring municipalities to consider climate change in asset management planning in 2017 (Canadian Water Network, 2019). In other provinces, key water-related policies, such as the Water Modernization Act in British Columbia, the 25 Year Water Security Plan in Saskatchewan and Guides to Water Withdrawal Approvals in Nova Scotia, are instrumental in supporting social networks and self-organization. For example, policies may provide extension services through field days and meetings, piloting the application of suggested practices, supporting local advisory committees, and offering workshops in key areas such as new standards and guidelines (Bizikova et al., 2013).

Risk-sharing policy tools are another way of enhancing capacity to address water-related climate change issues. There are a variety of risk-sharing tools available to Canadian municipalities to address flood risk, including disaster assistance programs that share the cost of recovering from disasters between the federal and provincial governments (e.g., the Ontario Municipal Disaster Recovery Assistance Program, the Alberta Disaster Recovery Program, the Saskatchewan Provincial Disaster Assistance Program, etc.) (Morrison et al., 2018; Thistlethwaite and Henstra, 2017). While there is a diversity of policy approaches to flooding in Canada (Morrison et al., 2018), cities do not always take advantage of the full suite of risk-sharing tools available (Thistlethwaite and Henstra, 2017). For example, both Calgary and Toronto attach a fee to property taxes and utility bills to fund flood mitigation and adaptation infrastructure, but do not employ a risk-based charge (a charge that is roughly proportional to the property's contribution to urban flood risk), as a means of incentivizing the uptake of property-level flood protection (Thistlethwaite and Henstra, 2017). Alternatively, Edmonton, Mississauga, Kitchener and Waterloo are examples of municipalities that charge user fees for storm water management that is roughly based on how much the property contributes to runoff (EPCOR, 2019; Aquije, 2016). While there are many methods to fund storm water management, including property taxes, development charges and intergovernmental transfers, user charges can provide a good balance of stability in revenue intake and equity (Aquije, 2016).

Organizations are finding ways to maintain valuable institutional knowledge while linking to a variety of knowledge communities in order to improve understanding of water management issues and potential solutions. For example, for the Prairie Provinces Water Board, contextual knowledge of working in an interjurisdictional context is very important. To ensure that this knowledge is maintained through turnover in members, the Board has begun a process of succession planning whereby each member identifies an alternate who shares their responsibilities and can therefore act as a replacement as turnover occurs (Global Water Futures, 2020). Indigenous Knowledge is also becoming more explicitly recognized in water research, and in the mandates and practices of water organizations. For example, the Northern Voices, Northern

Waters Strategy of the Northwest Territories explicitly includes provisions for recognizing Indigenous rights and considers Indigenous Knowledge equivalent to science (Global Water Futures, 2020; Sandford et al., 2011). Similarly, the Red River Basin Commission signed a Memorandum of Understanding with the Southern Chiefs Organization in Manitoba, committing both partners to work collaboratively on issues such as deteriorating water quality and flooding (Southern Chiefs Organization, 2018). In Mittimatalik (Pond Inlet), Nunavut, youth and supporting partners use traditional knowledge from community Elders in tandem with Western scientific methods, such as water sampling, to study the increasing frequency of gastrointestinal illnesses in the community (Inuit Tapiriit Kanatami, 2019). Successful integration of Indigenous Knowledge can reveal variables previously unaccounted for (Sandford et al., 2011) and provide additional evidence about the meaning of change (Abu et al., 2019), though it can be challenging in practice (Mantyka-Pringle et al., 2017). For example, while the Mackenzie River Basin Board has a mandate to include Indigenous peoples and integrate Indigenous Knowledge, it is difficult to adequately represent the diverse interests and knowledge of the many unique Indigenous communities in the Mackenzie River Basin's work (Morris and de Loë, 2016).

Partnerships can also involve sharing power over decision making, such as in the case of the co-management arrangements that have resulted from negotiated land claim agreements with Indigenous nations across Canada (Latta, 2018; Zubrycki et al., 2016). For example, in the Northwest Territories, the Mackenzie Valley, Sahtu, Gwich'in and Wek'èezhii are four land and water boards that involve the co-management of natural resources by the territorial and federal governments of Canada, and the governments of some of the Indigenous peoples who occupy those territories (Tsatsaros et al., 2018; Canadian Council of Ministers of the Environment, 2016). These co-management arrangements have been implemented with mixed success, but, overall, it is believed that they increase access to resources, and contribute to processes of social learning and knowledge exchange—particularly the bridging between Indigenous Knowledge and scientific knowledge (*see* Section 4.4.4, Mantyka-Pringle et al., 2017; Armitage et al., 2011).

4.3.4 Conclusion

Adaptation offers opportunities to address vulnerabilities in our water resources systems. Overall, progress in coordinating adaptation efforts in the water sector is uneven across Canada. Local communities, and Indigenous and civil society organizations are becoming more involved in water governance, yet often have limited capacity to effectively address impacts from climate changes. New organizational arrangements, such as water-based networks, offer an opportunity to draw on existing capacity and coordinate effectively among the myriad participants involved in adaptation to reduce the water-related risks of climate change.

4.4 Adaptation is advancing through innovation and adaptive management

There are promising examples of coordination and innovation in the water sector across Canada. New approaches use scenarios to explore how decision-making strategies perform across a range of plausible futures, implement iterative processes for monitoring and adjusting actions, and engage stakeholders in social learning, laying the groundwork for innovation and adaptation.

While institutional barriers remain, innovations around water management and climate change adaptation have occurred across Canada. Innovation in the water sector is driven by leaders who propose new ideas and build coalitions around them, and by the creation of safe spaces for policy experimentation. Exploratory modelling and scenario exercises can build empathy and consensus between stakeholders and lead to the development of low- or no-regret adaptation strategies that perform reasonably well against a wide range of plausible futures. Adaptive management provides a systematic, iterative process of monitoring and adjusting actions to new information and changing circumstances.

4.4.1 Introduction

Managing uncertainty is a key component of adaptation planning in the water resources sector. The same hydrologic or water quality model with slightly different inputs of initial environmental conditions can yield very different results, particularly at local and regional scales where most adaptive action takes place (Gober, 2018). Adaptive management aims to anticipate a wide range of future conditions and to reduce risk exposure (Hurlbert, 2018), leading to decisions that are more robust in the face of these uncertainties.

4.4.2 Institutional barriers to innovation

Inflexible institutional governance, water system design and planning can limit the ability of the water sector to adapt to climate change impacts. Many Canadian water systems were historically designed around the needs of influential regional groups with primarily single-use interest in water, such as irrigation or hydropower (Heinmiller, 2017; Clancy 2014). As such, policy and management failures can result from fixed commitments, such as water allocation rules based on historical appropriation that does not consider ecosystem needs or equitable distribution for newer users (Sandford et al., 2011; Hamlet, 2011). Effective adaptive governance systems are dynamic, analytical, nimble and responsive to current and emerging needs (Cosens et al., 2017; Hurlbert and Diaz, 2013); however, institutional support for flexible, diverse programming to encourage proactive policy design is not always available (Global Water Futures, 2020; Sandford et al., 2011; Ivey et al., 2004). For example, the absence of a flexible regulatory framework and clear legal system around water reuse rights limits the adoption of demand-side management approaches to water conservation in Alberta (Alberta WaterSMART, 2013). Similarly, there is little in terms of water and ecosystem services market development in Canada, which impedes competition for conservation and wetland retention activities on private land (Global Water Futures, 2020). Actions to redesign or improve the institutional systems, including infrastructure upgrades (Sandford et al., 2011), and policy and administration processes (Straith et al., 2014; Patino, 2010), are sometimes accompanied by high financial and political costs that can be a barrier to action.

Despite these institutional barriers, there are pockets of innovation in the water sector across Canada. At the provincial level, the past two decades have seen many water policy reforms, with renewed focus on drinking and source water protection, and a rise in watershed-based decision-making organizations (Bakker and Cook, 2011). Some notable water management modernizations include Alberta's water markets, the Northwest Territories Northern Voices, Northern Waters strategy, which prioritizes water for nature, and Ontario's requirements for full-cost pricing and accounting for water supply infrastructure (Global Water Futures, 2020; Bakker and Cook, 2011; Sandford et al., 2011). Innovation often stems from supportive local factors and the creation of safe spaces for policy experimentation (Moore et al., 2014; Straith et al., 2014).

4.4.3 Leadership and water champions

Adaptive organizations and policies require strong leadership to foster an institutional culture of innovation (Dale et al., 2019; Burch, 2010), take necessary risks to carry out mandates (Mitchell, 2017; Morris and de Loë, 2016; Hurlbert and Diaz, 2013), and successfully implement and follow through with adaptation plans (Zubrycki et al., 2016; Simms and de Loë, 2010). Leadership can play an important role in empowering water practitioners to do their best work, especially in a fragmented policy context where there is not always clear authority for adaptation work (Oulahen et al., 2018). For example, in the City of Vancouver, leadership by elected officials and city administrators was identified as critical to advancing flood risk adaptation efforts (Oulahen et al., 2018). Burch (2010) also details the actions of a persuasive practitioner within the City's Planning Department, who noticed that cultural conflicts between staff in planning and operations were slowing progress on adaptation, and intentionally hired staff who valued inter-departmental collaboration. These actions contributed to a paradigm shift within the City that has led to systems being highly responsive to dealing with a changing climate, given the vulnerabilities of Vancouver and its surrounding municipalities.

Water "champions" propose innovation, build coalitions to support it, and appeal to the interests and concerns of those in the decision-making network (Daniell et al., 2014). These individuals can work inside or outside of an organization (Moore et al., 2014), but are usually more successful if they have implementing capacity (Daniell et al., 2014). They are change agents, highly skilled at recognizing cultural and institutional characteristics that inhibit or promote changes, and strategies that can successfully influence implementation. They usually have strong informal and formal networks, are good communicators who are willing to take necessary risks, and are humble, respectful and open to new ideas. They may also be skillful at managing and brokering relationships between different water communities and other relevant sectors (Hurlbert, 2018; Straith et al., 2014). These skills are fostered by leadership training and negotiating opportunities.

4.4.4 Stakeholder participation and social learning

Social networks and social learning are linked with innovation in water institutions. Social learning means that people learn as part of a group from observing behaviours and their consequences. Social networks connect water practitioners to different types of knowledge and resources, facilitating understanding and trust (Moore et al., 2014; Gupta et al., 2010; Folke et al., 2005). Stakeholder engagement that incorporates social learning enables participants to explore adaptation options and confront the inevitable trade-offs associated with them.

Exploration of the future often involves exploratory models and participatory exercises to investigate a range of potential future conditions (Maier et al., 2016). Scenarios are consistent stories about the future for systems that are too complex to predict (Wiek et al., 2015). They cover the range of plausible futures (Lemieux et al., 2014), including rare but potentially devastating events such as the failure of critical infrastructure or energy systems. Scenario development often involves local stakeholders who share their (often competing) views of the future to facilitate robust decision making (*see* Case Story 4.4 and Case Story 4.5; White et al., 2015). A goal of these exercises is to develop strategies that perform reasonably well against a wide range of plausible climate change and societal forces, even when confronted by surprise circumstances (Lempert et al., 2003). They provide a solid basis for consensus building and political action among stakeholders with different views of the future, because they provide a reasonable outcome no matter whose view of the future proves to be correct. They can also identify “no” or “low regret” strategies that increase climate resilience and also promote good water management broadly, often at little additional cost. Examples of these types of strategies include the following: enhancing operator training and improving coordination (Casello and Towns, 2017); upgrading monitoring networks contributing to forecasting (Canadian Council of Ministers of the Environment, 2011); and water conservation and demand management (Mguni, 2015; de Loë et al., 2001). The latter is identified as important in the municipal sector in Ontario and in the Alberta Water for Life Strategy, resulting in an improvement in water use efficiency and productivity in Alberta by 30% between 2005 and 2015 (Alberta Water Council, 2017). In addition, scenarios can help identify potentially maladaptive behaviours, such as increased consumption, that could be associated with major capital projects (de Loë et al., 2001).

Case Story 4.4: Addressing climate vulnerability and sustainable water management in the South Saskatchewan River Basin

Southern Alberta has recently experienced disastrous floods and droughts. Added pressures from a growing economy, an expanding population and changing climate have significantly challenged the management of water resources in the South Saskatchewan River Basin (SSRB), and will continue to do so. To address these challenges, the Alberta WaterSMART project worked with representatives from irrigation districts, municipalities and watershed organizations to develop a set of plausible future water supply and demand scenarios for the SSRB. The scenarios linked data from historic drought and flood years with future climate projections, and also considered potential future land use and societal changes, such as wetland restoration, a major forest disturbance in the headwaters, increased water demands and possible decreased flows from the United States of America, resulting from changing glaciers extents and precipitation patterns attributed to climate change.

Working groups were asked to develop a list of adaptation strategies to address the high- and low-flow conditions that could result from each scenario (Alberta WaterSMART, 2016). A suite of performance measures were developed to help participants evaluate the success of each strategy. Performance measures reflected a desired water outcome for the SSRB or its sub-basins, and included metrics such as the "percentage of days when instream fish needs were not met" or "maximum flow violations." The performance of each adaptation strategy was assessed using a water resources model designed for the SSRB. Participants used results from model runs to sort adaptation strategies into different levels, from strategies that could improve current conditions to those that would make the basin more resilient to climatic changes in the future. Strategies considered most promising by the group of multiple stakeholders for the SSRB included (Alberta WaterSMART, 2016):

- developing shortage-sharing frameworks by sub-basin;
- restricting greenfield development in the floodplain;
- redesigning operating policies for upstream Bow River reservoirs; and
- building net storage flow in the Bow River sub-basin.

Case Story 4.5: Lake Superior and Lake Ontario outflow regulation: Addressing uncertainty in Great Lakes water levels

Water levels of the Great Lakes are driven primarily by natural factors, including changes in precipitation and temperature (*see* Case Story 4.1), but are also partially affected by regulation of outflows from Lake Superior and Lake Ontario through dams and related control structures on the Saint Mary's River and dams at Cornwall-Massena on the St. Lawrence River. Outflows are managed using regulation plans—rules that guide how much water is released through the regulatory structures under widely varying hydrological and climatic (hydroclimate) conditions to meet the needs of various water-using interests throughout the basin. The International Joint Commission (IJC) conducted studies (International Upper Great Lakes Study Board, 2012; International Lake Ontario–St. Lawrence River Study Board, 2006) to evaluate alternative regulation scenarios to address emerging needs and to consider climate change, and also used scenario analysis to review the rules for regulating outflows in the context of climate variability and change, and to better balance the water needs of diverse interests in the region.

The IJC studies included detailed hydroclimatic analysis to inform assessment of the current state of water resources modelling in the region, the construction of a timeline of historical climate variability, and the downscaling of global climate models to understand the impact of climate change on future regional water levels. This analysis revealed considerable uncertainty around how water levels could change in the future, using different hydroclimatic scenarios to represent a wide range of plausible future conditions including:

- historical (assumed stationary) climate to anticipate the next 30–100 years;
- a large, 50,000-year sequence of stochastically-generated water supplies to each of the Great Lakes to capture a full range of climate variability (based on historical water supply conditions); and
- a changing climate leading to decreased and/or increased water levels.

At the same time, researchers worked with stakeholders to define water interests in the basin, such as hydroelectric generation, commercial navigation, shoreline properties, recreational boating, municipal and industrial water uses and ecosystems, and their potential vulnerabilities to fluctuations in water levels. Performance indicators and/or coping zones (i.e., the range of conditions that would be considered tolerable) were derived for each interest, and a relationship between these and water levels was determined. Public and expert feedback led the Study Boards to recommend that the new regulation plans should improve the health of the environment, minimize damage from water-related natural hazards, and increase or maintain the economic viability of shipping, hydropower, recreation/tourism and industry.

Study participants then tested different sets of regulation plans using a "shared vision model" (SVM), a user-friendly computer platform that allowed the collaborative development of models and operating plans to simulate impacts in the basin. Participants used the SVM to compare the performance of the current regulation plan to that of alternative plans under a range of hydroclimate scenarios, and drew upon the performance indicators and coping zones to explore trade-offs associated with alternative plans.

Through this process, the Study Boards in each study narrowed down alternative regulation plans to those that were more robust to changing conditions, continued to balance upstream and downstream impacts and benefits, and promoted more natural flows and ecosystem benefits under a range of hydroclimatic conditions. After considerable public and government consultation, the IJC implemented a new plan for regulating Lake Superior outflows (Plan 2012) at the beginning of 2015, and in January 2017, adopted Plan 2014 for regulating Lake Ontario outflows. An adaptive management strategy was developed to complement these new regulation plans as a means to review and refine the chosen regulation plans over time if conditions in the system changed. Adaptive management compares observed outcomes through on-going monitoring to the simulated results to improve the simulations over time. The on-going performance of the regulation plans can be assessed under a range of water level conditions and the regulation plans can be formulated and evaluated as more is learned and as conditions change. The final reports from these studies and the adaptive management process are available from the IJC website (ijc.org).

4.4.5 Adaptive management and water experiments

Many water planners seek adaptation measures that are robust under a wide range of possible future climate conditions. While there is no standardized paradigm for quantifying robustness in the water sector (Whateley et al., 2016), the idea of robustness generally implies acceptable performance over a wide range of future scenarios (Lempert and Groves, 2010; Groves and Lempert, 2007; Lempert and Collins, 2007). Therefore, decision makers need the ability to both assess how well decisions meet expectations and to adapt those management decisions as more information is received and conditions change. Adaptive management accepts that decisions are made with imperfect information and under high degrees of uncertainty, and provides a means for reviewing the performance of a decision through on-going monitoring of outcomes and stakeholder preferences, updating the modelling and evaluation tools used in the original decision, and recommending improvements as necessary (International Upper Great Lakes Study Board, 2012) (*see* Box 4.2). In adaptive management, adaptation actions and policies are designed to be flexible and are subject to adjustment in an iterative, social learning process (Lee, 1999).

Box 4.2: Adaptation vs. adaptive management

Adaptation actions are interventions taken to respond to new or different information obtained through monitoring and experience. Simply stated, adaptation is about taking action to change something if it is not working. In current practice, questions of how to measure vulnerability, adaptive capacity, and resilience for effective adaptive actions are a challenge for policy makers and scientists (Lesnikowski et al., 2017). Adaptation is complex across multiple sectors and disciplines, and there is no single, universal metric that fits the reality of adaptation (Ford and King, 2015). In an examination of 15 scientific studies around water resources adaptation strategies, Salerno (2017) found that a common weakness of adaptation strategies is identifying approaches to address uncertainty (Woodruff, 2016). Specifically, adaptation plans commonly fail to provide detailed implementation processes, raising concerns about whether adaptation actions will translate into reductions in vulnerability or maladaptation (Salerno, 2017).

Adaptive management is an approach to adaptation that embraces risk and uncertainty as a way of building understanding based on continuous monitoring, predictive modelling, evaluation and learning. Adaptive management provides a structured, iterative process of robust decision making in the face of uncertainty, with the aim of reducing uncertainty over time via system monitoring (Williams and Brown, 2014). Adaptive management recognizes that:

- no matter how much we know, there is always more to learn;
- conditions are always changing, sometimes in ways that cannot even be imagined, let alone predicted; and
- decisions are made based on the best, albeit imperfect, evidence available and may not always be effective.

The concept of adaptive management is to challenge decisions (such as adaptive actions) if outcomes are not as expected and to make necessary adjustments as more is learned and/or as conditions change. Simply put, adaptive management goes further than adaptation by following up on actions to ensure that they are working as intended and, if not, to make adjustments (*see* Figure 4.4). Adaptive management requires good planning, collaboration and quantitative predictive modelling. A successful adaptive management strategy aims to develop and apply multi-objective, flexible and sustainable solutions through collaborative efforts that include (International Great Lakes–St. Lawrence River Adaptive Management Task Team, 2013):

- monitoring and modelling for improved understanding of:
  - why and how conditions are changing;
  - existing and potential risks and complexities of problems; and
  - performance metrics for understanding the success of options;
- tools for developing and evaluating adaptive options;
- transparent, accessible information readily available to users;
- on-going assessment and evaluation of solutions maintained with feedback to decision-making processes; and
- stakeholders that are fully engaged with mechanisms to inform the decision-making process.

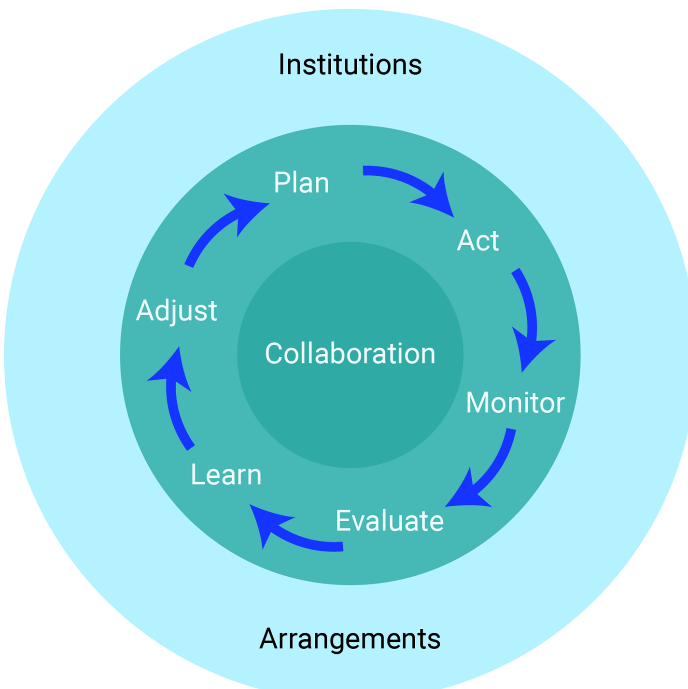

Figure 4.4: Diagram illustrating the adaptive management cycle. Source: Adapted from International Great Lakes–St. Lawrence River Adaptive Management Task Team, 2013.

Evidence suggests Canadian water management frameworks vary in their ability to respond to unanticipated events. Bizikova et al. (2013) examined water-related policies in British Columbia, Saskatchewan, Manitoba and Nova Scotia to assess the elements representing adaptability, such as multi-stakeholder deliberation, automatic policy adjustment, and integrated and forward-looking analysis. They found that these policies do not always include explicit monitoring and review processes (Bizikova et al., 2013). In some cases, formal reviews were completely absent (Roy, 2013), whereas in other instances, reviews were spontaneous or only done once, not feeding back into formal policy reviews and adjustments (Bizikova and Vodicka, 2013). In about half of the policies examined, a formal review was required, but no public report of this review was available, and no information on subsequent policy adjustment was required (Bizikova et al., 2013). Ultimately, the team examined 27 policies from the water sector, as well as the agriculture and forestry sectors, and scored them using the ADAPTool method, which assesses the adaptability of policies or programs in relation to any defined stressor or external change, such as climate. Despite the wide range of policies making it difficult to compare across jurisdictions, the team found a wide range of adaptability in the policies present (*see* Figure 4.5). High-scoring policies (in the green zone) were generally not vulnerable themselves to climate change, played a role in building adaptive capacity of groups, and were designed to use multi-stakeholder processes and/or foresight methods such as scenario analysis (Bizikova et al., 2013).

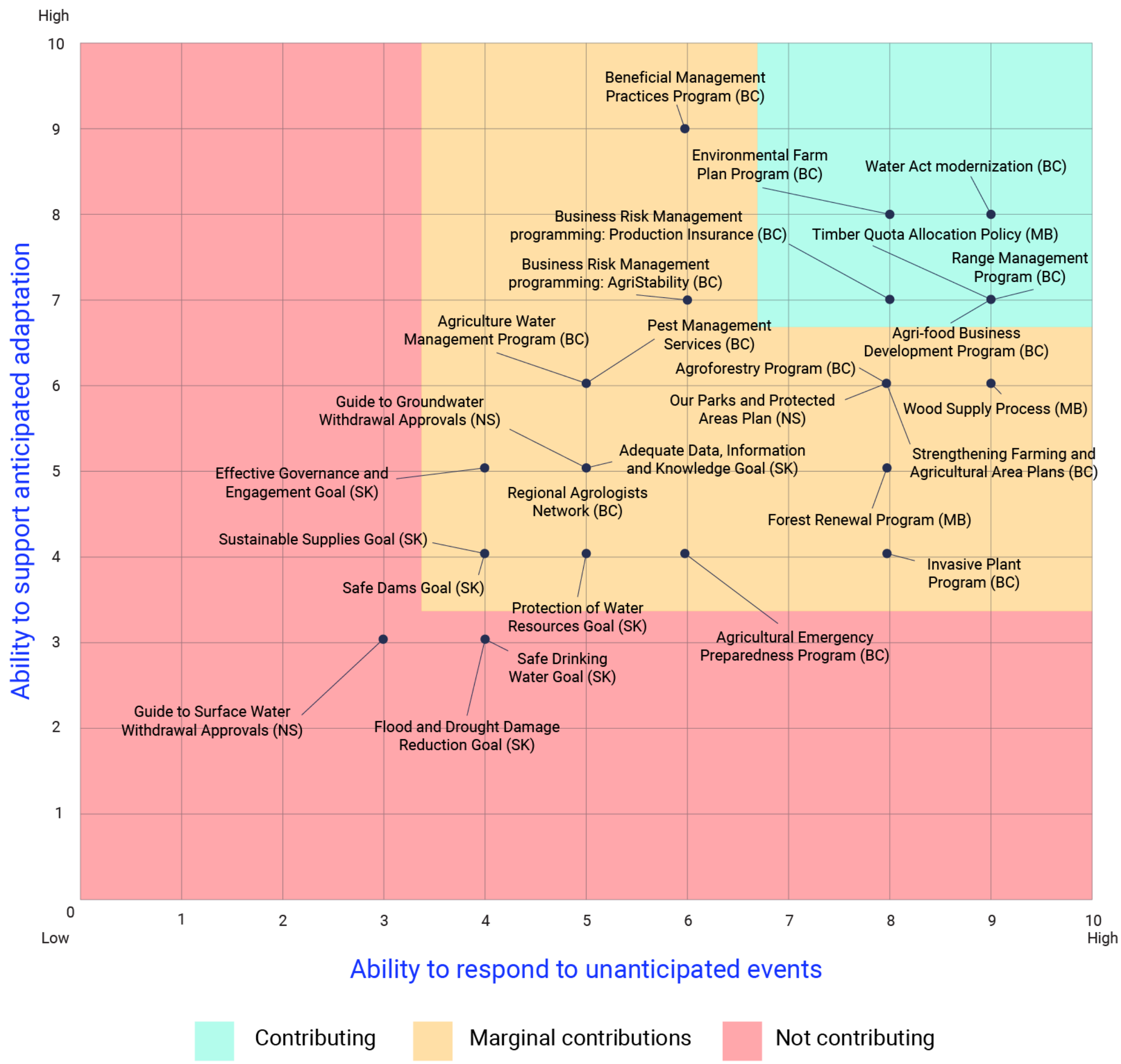

Figure 4.5: An overview of the ADAPTool Scoring Results (from 1 to 10) for 27 policies examined in British Columbia, Saskatchewan, Manitoba and Nova Scotia. ADAPTool is structured as a series of Excel spreadsheets that take analysts through a standardized step-by-step process to assess the ability of existing policies or programs to support adaptation measures and the general adaptability of the policies or programs themselves. Source: Adapted from Bizikova et al., 2013.

Adaptive management requires long-term commitments, collaboration (Global Water Futures, 2020) and funding, and an effective linkage of science-based monitoring to decision-making processes (Murphy and Weiland, 2014). While effective adaptive management is difficult to achieve, examples of this are reported in natural resource management broadly (Williams and Brown, 2014) and in the management of water resources in Canada (Failing et al., 2013). The 2012 Great Lakes Water Quality Agreement between the United States and Canada includes adaptive management as a guiding principle in order to systematically assess the effectiveness of actions and adjust future actions to achieve the ecological integrity and water goals for the basin (IJC, 2017). An even more structured adaptive management effort was initiated for the Great Lakes in 2015 by the IJC with the establishment of the Great Lakes–St. Lawrence River Adaptive Management (GLAM) Committee to provide on-going review and evaluation of newly implemented regulation plans of outflows from Lake Superior and Lake Ontario (IJC, 2015) (*see* Case Story 4.5). This initiative provides a structured approach to adaptive management to respond to climate changes and links the evaluation of plan performance directly to the IJC as the decision makers (Clamen and MacFarlane, 2018; Great Lakes–St. Lawrence River Adaptive Management Committee, 2018).

4.5 It is vital to engage the public and build awareness about adaptation opportunities

Successful adaptation requires public buy-in to the science of climate change and the need to implement adaptation policies. A majority of Canadians support policies to address water-related problems, but managing water resources ranks low on their list of salient problems after the economy, health care and cost of living. Extreme events, including floods, droughts and episodes of poor water quality, can often bring the need for better water management to the forefront.

Canadians are concerned about water and want governments to play a strong role in instituting practices that protect water resources and prepare for water-related hazards. Lack of issue salience, misperceptions about how water systems function, and financial and technical barriers can impede the buy-in for climate change adaptation. Water practitioners are fostering public support by emphasizing financial and health-related co-benefits, addressing barriers to action, and taking advantage of highly publicized water-related events. The discourse around options for adaptation in the water sector is expanding to include a wider variety of policy tools to address water issues.

4.5.1 Introduction

Water in Canada is generally perceived to be of high quality, abundant (Renzetti and Dupont, 2017; Royal Bank of Canada, 2017) and our most important resource (Royal Bank of Canada, 2017). However, Canadians make large per capita water withdrawals compared to those in other countries—which include consumptive and non-consumptive uses (Conference Board of Canada, 2013)—and water policy issues are ranked among the lowest in public opinion surveys—regarded as much lower in importance compared to the economy, healthcare and the rising cost of living (*see* Figure 4.6; Royal Bank of Canada , 2017; Clancy, 2014). These perceptions ultimately influence policy development (Heinmiller, 2017; Yates et al., 2017; Clancy, 2014) and can challenge efforts to implement adaptation strategies (Dale et al., 2019).

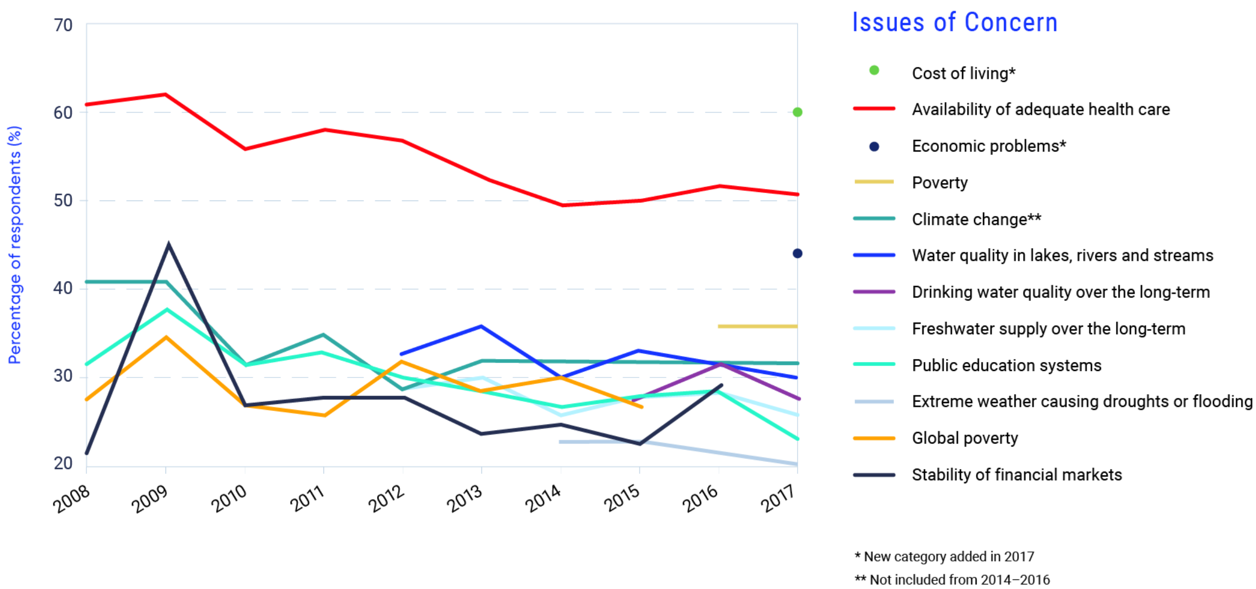

Figure 4.6: The annual RBC Canadian Water Attitudes Study, which asks respondents to indicate their degree of concern related to a range of issues, found that Canadians are concerned about water issues and climate change, but to a lesser degree than issues such as the cost of living, availability of healthcare and poverty. Source: Adapted from Royal Bank of Canada, 2017.

Practitioners in the water sector are working to influence perceptions in favour of proactive adaptation in the water resources sector (Global Water Futures, 2020). While improved scientific understanding can highlight trends, vulnerabilities and potential solutions to technical water management issues, decision makers must satisfy multiple, and often conflicting, needs and objectives (Bakker and Cook, 2011), and require processes that are responsive to public attitudes. Political turnover and the short time scales available for planning exacerbate this challenge (Dale et al., 2019; Hurlbert and Diaz, 2013; Hamlet, 2011).

4.5.2 Perceptions of water and climate

Perceptions about policy issues are important because they influence judgments around the acceptability or appropriateness of proposed solutions (Stone, 2002). According to surveys, most Canadians believe that climate change is occurring (Mildenberger et al., 2016; Lachapelle et al., 2014), and that climate change will have a negative impact on Canada's supply and quality of fresh water (Royal Bank of Canada, 2017). They expect more frequent and intense extreme storms, flooding of rivers and coastal areas, and lengthy droughts (Akerlof et al., 2010). Despite these concerns, Canadians' level of preparedness for water-related extremes has remained low for a number of years. In a survey by Royal Bank of Canada (2017) of over 2,000 Canadians, only 35% reported that they are prepared to deal with floods and drought. In another survey, almost all of the 2,300 Canadians surveyed believed that homeowners are primarily responsible for flood protection, but less than 30% pursue protective measures and only 6% know whether they live in a designated flood-risk area (Henstra et al., 2019b; Thistlethwaite et al., 2017).

Despite some skepticism, there is widespread support for climate policy and government action to protect water resources as an alternative to “doing nothing” (Comeau, 2017; Mildenberger et al., 2016). Canadians want governments to play a strong role in managing water resources and in preparing for natural hazards (*see* Figure 4.7; Henstra et al., 2019b; Royal Bank of Canada , 2017), to enforce stricter regulations, and to require commercial and industrial users to pay full water supply costs (Real Estate Foundation of British Columbia, 2018; Royal Bank of Canada, 2017). This support can diminish, however, due to issue fatigue and politicization of the climate change issue (Groulx et al., 2014; Pidgeon, 2012).

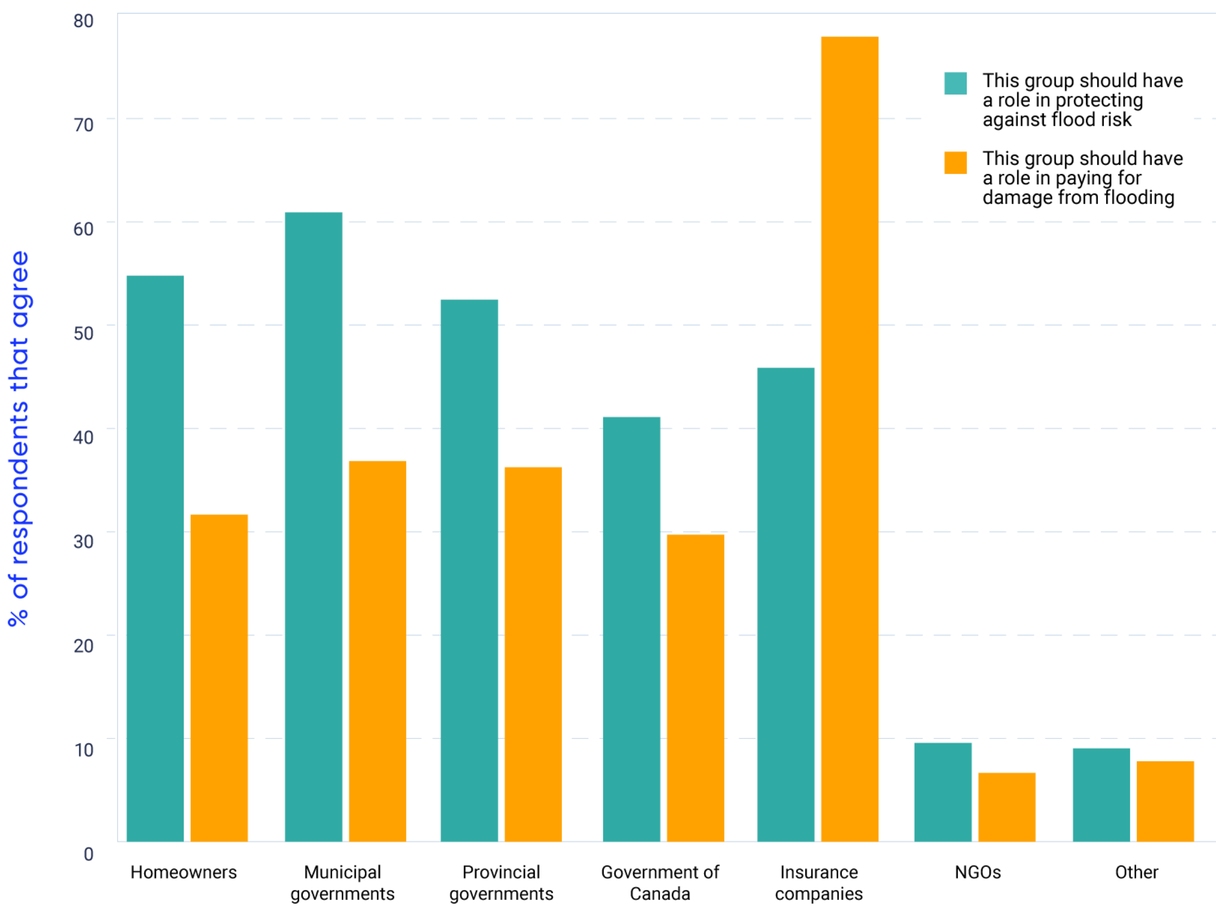

Figure 4.7: A 2016 national survey of Canadians living in “flood risk areas” (as defined by Government of Canada, 2013), developed by researchers at the University of Waterloo, evaluated perceptions about how the responsibility associated with protecting their property and paying for costs related to flood damage should be shared between different organizations. Source: Adapted from Thistlethwaite et al., 2017.

4.5.3 Building public support for adaptation

The inconveniences of maintenance and the “invisible” nature of water services are additional challenges to garnering public support for adaptation in the face of a changing climate (Canadian Water and Wastewater Association, 2015). Quite literally, most water-related water infrastructure is “out of sight, out of mind.” Most water managers and regulators view ageing infrastructure as the most prominent future risk to the Canadian water sector (Global Water Futures, 2020; Moncrieff-Gould et al., 2018), yet only one in five Canadians believe that major investments in water-related infrastructure are required (Royal Bank of Canada, 2017). Building public support through emphasizing health, economic and environmental benefits of investments in water systems may increase the likelihood that decision makers will set water systems as a priority for action (Canadian Water and Wastewater Association, 2015). This process can involve framing water-related climate information in positive terms paired with consistent and constructive solutions (Global Water Futures, 2020; Canadian Water and Wastewater Association, 2015; Patino, 2010), mainstreaming climate solutions within other policy areas such as urban development (Dale et al., 2019) and engaging stakeholders early and substantively in adaptation processes (Lemieux et al., 2014).

Canadians want information about water-related risks to be relevant to the issues that they care about, and want to know what to do with that information (Jones-Bitton et al., 2016; Henrich et al., 2015; Groulx et al., 2014). A recent survey of 2,300 Canadian households found that 92% of respondents want publicly available flood risk maps with flood mitigation information, and want access to this information when they are considering home ownership (Thistlethwaite et al., 2017). The climate change dimension may not matter if the benefits of the adaptation actions align with important values held by the target audience and lead to co-benefits. For example, despite the benefits for climate resilience, improved water quality is the main motivator for farmers restoring wetlands in Nova Scotia (Sherren and Verstraten, 2013). Other studies have found that framing water management policies in terms of personal benefits, such as a lower cost of living, sustainable economic development, and lower incidence of disease, have more appeal to a wider range of people (Henrich et al., 2015; Groulx et al., 2014; Semenza et al., 2011; Akerlof et al., 2010). With the necessary information, individuals who feel personally at risk tend to be more prepared (Semenza et al., 2011).

Financial and time constraints are also issues that can prevent or slow adaptive behaviour (Groulx et al., 2014; Semenza et al., 2011). Efforts to reduce these barriers and promote behavioural change through the formation and dissemination of social norms, self-perception and memory prompts have been effective across Canada (Lieske et al., 2014; Lo, 2013; McKenzie-Mohr, 2000). For example, after identifying financial constraints as a major barrier to the adoption of water conservation behaviours, the City of Barrie, Ontario, introduced a rebate program and an interest-free pay-back scheme for water-efficient appliances and their installation, ultimately deferring millions of dollars in water infrastructure spending (Reily, 2004).

Extreme water-related events, such as floods, droughts and water quality crises, provide a window of opportunity for political and policy action that can enhance long-term climate resilience (Dale et al., 2019; Oulahen et al., 2018). Many successful adaptations in the water sector have been driven by institutional responses to a public crisis (Clancy, 2014). This occurred after floods and freeze-thaw events that caused significant road damages initiated a major adaptation process in Prince George, British Columbia (Dale et al., 2019), and when source water protection was strengthened after water contamination incidents in Walkerton, Ontario (in 2000) and North Battleford, Saskatchewan (in 2001) (Hurlbert et al., 2015; Bakker and Cook, 2011;

de Loë and Plummer, 2010). Similarly, significant flooding in 2011 and 2014 to downstream communities in Manitoba brought renewed attention to the flood control benefits of wetland retention, whereas previous attempts focusing on biodiversity protection failed to motivate political action (Global Water Futures, 2020). As a result, the Sustainable Watersheds Act was passed into law in 2018, employing a combination of economic incentives and disincentives, and regulation to promote a "no net loss of wetlands" policy in the province (Stevenson, 2018).

Water practitioners across Canada employ a number of strategies to increase issue saliency around the water-related risks of climate change. They will be required to draw on these strategies and innovate even more as water systems become increasingly complex and uncertain, and the stakes to win over public perceptions become more critical.

4.5.4 Diversifying policy tools

Traditional approaches to water resource issues have been regulatory in nature (Simms and de Loë, 2010), but researchers and practitioners are increasingly recognizing that acting with conventional policy tools will not be enough to adapt to the growing complexity in water systems (Simms and de Loë, 2010; Hurlbert et al., 2010; Okanagan River Basin Board, 2010). Innovations and variation in policy design and implementation can reduce risks, increase the chances of reaching desired outcomes, and meet diverse stakeholder needs (Bizikova et al., 2018; Thistlethwaite and Henstra, 2017). Conversations around policy options and adaptation strategies are expanding at all levels (*see* Case Story 4.6), and there now exists a diverse mix of regulatory, expenditure, institutional and economic instruments in water policies across Canada (Bizikova et al., 2018).

Case Story 4.6: The changing policy discourse for solutions to water-related hazards in the Canadian Prairies

Much of the population in the Prairie provinces of Alberta, Saskatchewan and Manitoba obtains its water from the Nelson-Churchill River Basin, the third largest watershed in North America (*see* Figure 4.8; International Institute for Sustainable Development, 2016).

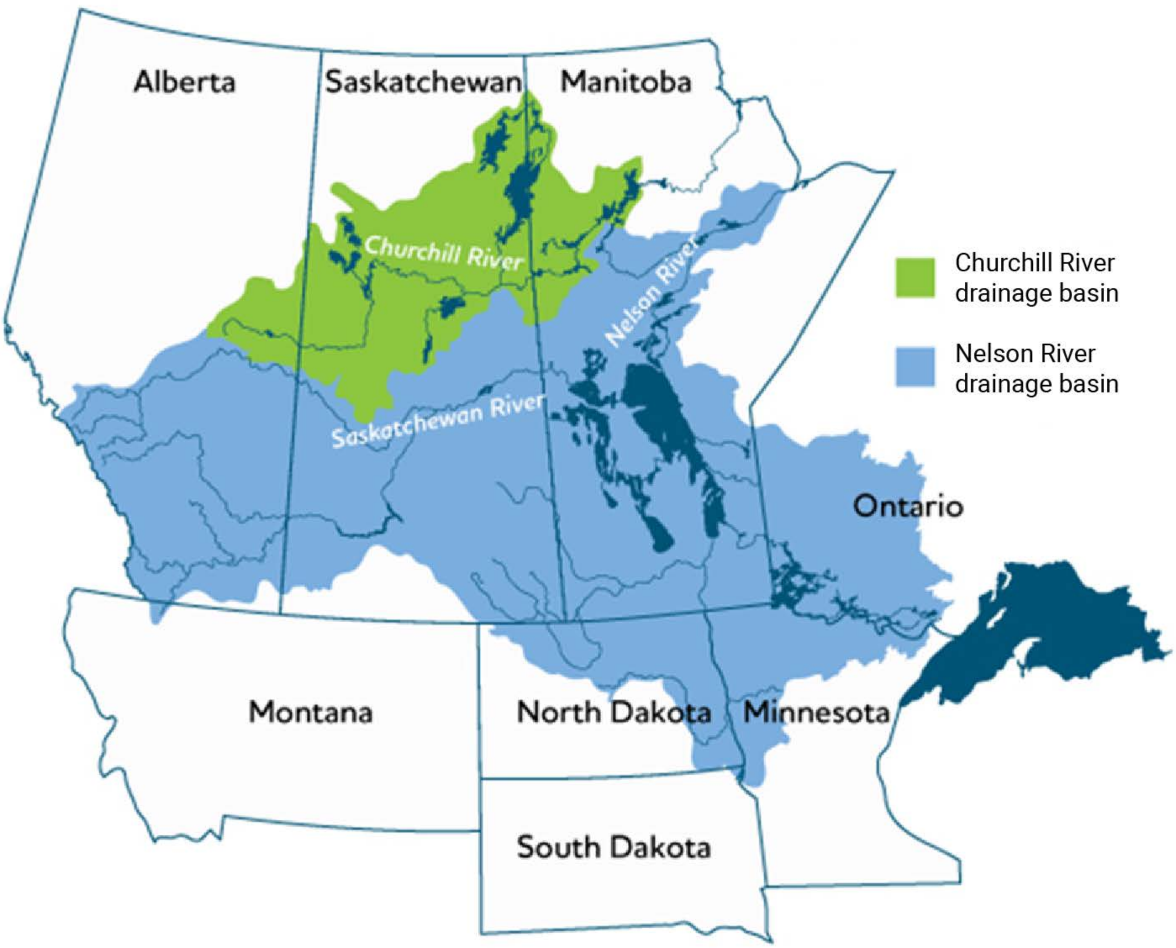

Figure 4.8: The drainage basins of the Nelson and Churchill Rivers. Source: Manitoba Hydropower, n.d.

In this basin, numerous organizations advocate for diverse approaches to address current water management that will likely be exacerbated by climate change (Global Water Futures, 2020). A wide range of policy approaches is discussed (*see* Figure 4.9). In policy and planning documents authored by different organizations operating within the basin, infrastructure solutions are the most discussed approach to address floods and droughts across the drainage basin. While built infrastructure approaches are most frequently referenced, natural infrastructure approaches are also mentioned and sometimes preferred, such as in the case of improving water quality (*see* Table 4.1).

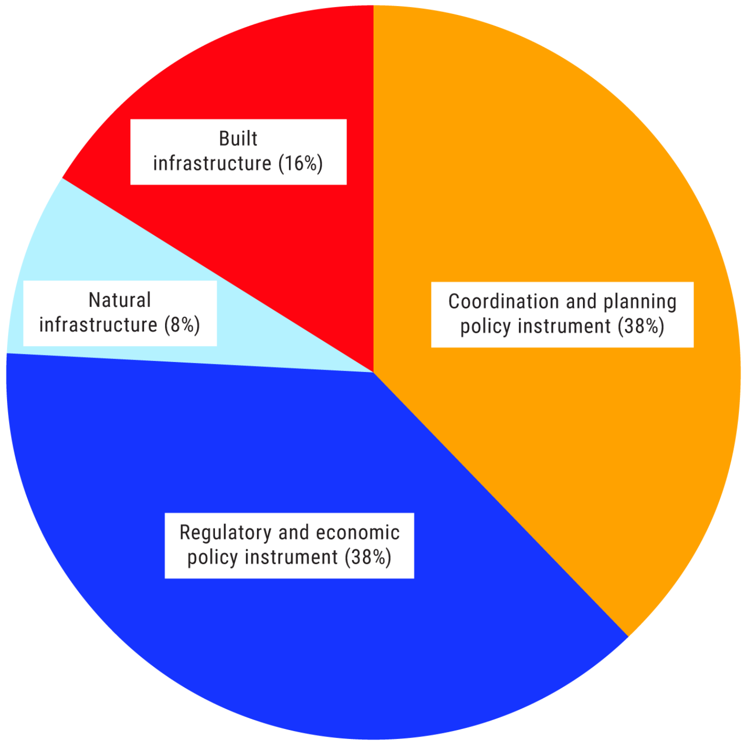

Figure 4.9: Percentage of dialogue in policy and planning documents across the Nelson–Churchill basin related to four policy instruments for addressing water issues. See Table 4.1 for specific examples.

Table 4.1: Examples of policy instruments and options to address water-related hazards in the Nelson–Churchill River Basin

BUILT INFRASTRUCTURE	NATURAL INFRASTRUCTURE	COORDINATION AND PLANNING	REGULATORY AND ECONOMIC
• Dyke and floodway construction • Installing tile drainage • Upgrading spillways and dams to new design standards for extremes	• Retaining and restoring wetlands • Increasing soil organic matter on agricultural lands	• Emergency response planning • Cooperative agreements • Coordinated drought and flood plans	• Mandated water rationing • Legislated penalties for drainage • Compensating flood victims • Tax credits for riparian (land along the banks of rivers and streams) management • Water pricing or surcharges
Source: Global Water Futures, 2020.			

Improving coordination and organizational policies across the basin is widely discussed as a means to enhance capacity to respond effectively to water-related hazards. This involves proactive planning (e.g., coordinated strategies for drought, wetlands and drainage, and invasive species), increasing financial and human resource capacity (e.g., reliably funding water resource groups, providing technical support to communities, increasing funding opportunities), and developing operating rules and procedures to enhance resilience to cope with new extremes. An example of the latter is the five-year agreement between TransAlta and the Government of Alberta that allows Alberta Environment and Parks to modify the levels of TransAlta-owned reservoirs on the Bow River for the purposes of enhancing flows during dry years and providing additional storage during wet periods (Government of Alberta, 2018).

There are differences in strategies and advocacy approaches across organizations with different roles in water governance (Global Water Futures, 2020). For example, environmental and non-profit groups tend to favour information provision and community engagement work, and prefer a regulatory-based approach to water management, whereas agricultural and industry organizations preferentially discuss market-based solutions to water management challenges, such as funding infrastructure upgrades to improve efficiencies, subsidizing best management practices and establishing insurance schemes.

4.5.5 Conclusion

Adapting to climate change in the water sector involves strengthening water planning and management capacities and mobilizing public support for investments, and institutional and behavioural change. Multi-sector engagement and enhanced opportunities for social learning amongst scientists, water professionals, civil society organizations and the general public are essential to building a social infrastructure that promotes adaptive decision making in the water sector. Shared learning about the need for action and the consequences of inaction would increase public support for policy action.

4.6 Water system vulnerability can be reduced through quality data and resilient design

Reducing vulnerabilities in water systems involves identifying weak spots under current and future climate conditions, and providing access to high quality and locally relevant data. While the quality and resolution of data for monitoring change in uncertain environmental systems is variable, resilient design practices are emerging.

Since there are limited resources to address the broad range of complex and widespread water challenges, it is important to identify areas and sectors that are particularly vulnerable to climate change and require specific management attention. To address vulnerabilities, practitioners require access to high quality and locally relevant data. While there are many information sources, at various scales, about water systems and future climate change impacts available across Canada, there is considerable variation in quality, and in temporal and spatial resolution of the available data. Infrastructure design and management is often based on historical information that no longer has the same relevance in a climate change context. Requirements around design, building and operations are changing to address these vulnerabilities. The Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol (Engineers Canada, n.d.) and the use of natural infrastructure have emerged as key tools for addressing the climate change-related vulnerability of water-resource infrastructure in Canada.

4.6.1 Introduction

Climate and water-related vulnerability and risk assessments have been carried out extensively across the country at different scales and for different issues. For example, assessments have been conducted in the Atlantic region for coastal areas and water resources (e.g., AMEC Environment & Infrastructure, 2012; Cochran et al., 2012; Ferguson and Beebe, 2012; Government of Newfoundland and Labrador, 2012); in Quebec for water quality and water use (e.g., Jalliffier-Verne et al., 2017; Tremblay, 2016; Carrière et al., 2010); in the Great Lakes Region for wetlands and aquatic ecosystems (e.g., Tu et al., 2017; Chu, 2015; Lemieux et al., 2014; Mortsch et al., 2006); in the Prairies for drought and flooding (e.g., Wittrock et al., 2018; KGS Group, 2016; Thomson Agri-Environmental, 2011a, b; Magzul and Rojas, 2006); in British Columbia for hydroelectricity and coastal flooding (e.g., Associated Engineering (B.C.) Ltd., 2018; Northwest Hydraulic Consultants Ltd., 2014; Jost and Weber, 2013); and in Northern Canada for thawing permafrost and vulnerable water supplies (e.g., BGC Engineering, 2011; Goulding, 2011; Nesbitt, 2010).

Syntheses of these assessments emphasize the diversity in methodologies and organizations (e.g., watershed organizations, academia, governments) involved (Perdeaux et al., 2018), as well as the technical challenges in identifying a range of climate change impacts and hazards on water resource systems (Nodelcorp Consulting, 2014). This is especially true for organizations with limited financial and technical capacity (Lemieux et al., 2014; Plummer et al., 2012).

4.6.2 Water information systems

Effective monitoring is a key element of successful adaptation (Hall et al., 2014). Water practitioners require access to high quality and locally relevant data because many fundamental water decisions are local in scale (Global Water Futures, 2020), and good information is necessary to assess vulnerabilities to climate change risks (Canadian Water Network, 2019). Unfortunately, high quality, systematic, regularized data collection is not the norm in many parts of Canada (Nodelcorp Consulting, 2014), and climate change impact data is not always available or linked into decision-making processes (Canadian Water Network, 2019). Key datasets for water practitioners are administered by a variety of federal departments, while provincial and territorial agencies provide information such as snow depth, stream flows and lake levels (*see* Table 4.2). Non-governmental organizations, such as B.C.'s Pacific Climate Impacts Consortium, the Prairie Climate Centre, the Ontario Climate Consortium and Ouranos, provide additional resources such as climate change and hydrologic scenarios. However, capacity to provide this information is uneven across organizations and governments, and data varies significantly in its quality, and temporal and spatial resolution (Koshida et al., 2015; Dunn and Bakker, 2011).

Table 4.2: A collection of national and regional water and climate change datasets, resources and tools

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Canada	The National Hydro Network (NHN) Geobase Series provides geospatial data and geometric attributes of Canada's inland surface waters.	Shapefiles	Pan-Canada	<https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977>
	The Canadian Tides and Water Levels Data Archive contains historical observations from Canadian and global monitoring sites.	Datasets	Pan-Canada (observations for up to 50 years, dating back to 1848)	<https://open.canada.ca/data/en/dataset/87b08750-4180-4d31-9414-a9470eba9b42>
	The Meteorological Service of Canada 50 North Atlantic Wave Hindcast provides hourly wind and wave time series data from climate hindcast models.	Datasets	Canadian East Coast for the period 1954–2018	<https://open.canada.ca/data/en/dataset/f3f0312d-d28b-400c-b14a-28f51ff7f08a>
Agriculture and Agri-Food Canada (AAFC)	The Drought Watch website provides information on drought conditions, soil moisture, and other climate variables.	Datasets and online mapping tools	Pan-Canada	<https://www.agr.gc.ca/eng/agriculture-and-the-environment/drought-watch/?id=1461263317515>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Agriculture and Agri-Food Canada (AAFC) (continued)	The AAFC Watershed project (2013) provides watershed related datasets for the Prairie provinces. Data includes drainage information, area of drainage, information on gauging stations, etc.	Datasets	Alberta, Saskatchewan, Manitoba, and some portions of British Columbia, Northwest Territories, Nunavut, and Ontario.	<https://open.canada.ca/data/en/dataset/c20d97e7-60d8-4df8-8611-4d499a796493>
Canadian Center for Climate Services (CCCS)	The CCCS provides access to a variety of climate datasets.	Datasets and online mapping tools	Pan-Canada	<https://www.canada.ca/en/environment-climate-change/services/climate-change/canadian-centre-climate-services/display-download.html>
Environment and Climate Change Canada	The Water Survey of Canada shows real time and historical hydrometric data collected from stations across Canada.	Datasets and online graphing tools	Pan-Canada	<https://wateroffice.ec.gc.ca/index_e.html>
Fisheries and Oceans Canada	The Canadian Extreme Water Level Adaptation Tool supports the adaptation of coastal infrastructure to water-related extremes.	Online application	Coastline of Canada	<http://www.bio.gc.ca/science/data-donnees/can-ewlat/index-en.php>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Natural Resources Canada	Canada's Climate Change Adaptation Platform provides links to various resources to support adaptation planning.	Collaborative forum with resources available for decision makers	Pan-Canada	<https://www.nrcan.gc.ca/climate-change/impacts-adaptations/adapting-our-changing-climate/10027>
	The Federal Flood Mapping Guidelines Series guide flood-mapping activities across the country (part of Canada's Platform for Disaster Risk Reduction).	Documents	Pan-Canada	<https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/fldpln-mppng-en.aspx>
Public Safety Canada	The Canadian Disaster Database provides information on Canadian and international disasters since 1900.	Datasets	Pan-Canada (1900–present)	<https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx>
Global Institute for Water Security	The Changing Cold Regions Network provides online access to water-related data and outputs from models and observatories.	Datasets	Pan-Canada	<http://www.ccrnetwork.ca/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
The Gordon Foundation	DataStream is an open access online data platform for sharing data across diverse data collection programs—from community groups to academic organizations. Datastreams exist for the Mackenzie, Lake Winnipeg and Atlantic Canada watersheds.	Datasets	Mackenzie, Lake Winnipeg and Atlantic Canada watersheds	<https://gordonfoundation.ca/initiatives/datastream/>
Government of Yukon	The Water Data Catalogue is an interactive map information on near real-time and historical water-related variables.	Interactive map with accessible data sources	Yukon	<http://yukon.maps.arcgis.com/apps/webappviewer/index.html?id=2365a4c0b8744f34be7f1451a38493d2>
Government of Northwest Territories	The NWT Discovery Portal allows users to browse, share and link a wide range of information, including water-related variables.	Variable	Northwest Territories	<http://nwtdiscoveryportal.enr.gov.nt.ca/geoportal/catalog/main/home.page>
	The Inventory of Landscape Change platform is an interactive map showing a variety of water variables.	Spatial data	Northwest Territories	<https://www.enr.gov.nt.ca/en/services/cumulative-impact-monitoring-program-nwt-cimp/inventory-landscape-change-webviewer>
Government of Nunavut	The Nunavut Water Board provides data on water licences and projects across the territory.	Interactive map and data	Nunavut	<https://www.nwb-oen.ca/nwb-license-map>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of British Columbia	The BC Water Resources Atlas displays various detailed water-related data.	Dataset and online mapping tool	British Columbia	<http://maps.gov.bc.ca/ess/hm/wrbc/>
	Change in Timing and Volume of River Flow in BC is a long-term hydrological dataset from 1912 to 2012.	Datasets, graphs and associated R code	British Columbia	<http://www.env.gov.bc.ca/soe/indicators/climate-change/rivers.html>
	The GeoWeb Water Portal displays historical and current water and climate data for stations across the province.	Interactive map and downloadable datasets	Northern British Columbia	<http://waterportal.geoweb.bcogc.ca/#12/54.3891/-126.7240>
	BC Water Tool displays watershed reporting, streamflow data, and groundwater and surface water quality data.	Interactive online map and downloadable datasets	Southern and coastal British Columbia	<http://kwt.bcwatertool.ca/streamflow>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of British Columbia (continued)	The Provincial Groundwater Observation Well Network displays data from 190 provincial monitoring stations.	Interactive online map and downloadable dataset	British Columbia	<https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-observation-well-network>
	Real-time Water Data for snow, groundwater, and hydrometric stations displayed on interactive map.	Interactive map and downloadable datasets	British Columbia	<https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/real-time-water-data-reporting>
	Change in Sea Level in BC (1910–2014) displays summary trends of sea level observations from four long-term monitoring stations.	Dataset	British Columbia	<https://www.env.gov.bc.ca/soe/indicators/climate-change/sea-level.html#:~:text=Average%20sea%20level%20has%20risen,centimetres%20per%20century%20at%20Vancouver>
Pacific Climate Impacts Consortium	Station Hydrologic Model Output provides simulated streamflow data for locations throughout BC.	Interactive map with downloadable datasets	British Columbia	<https://www.pacificclimate.org/data/station-hydrologic-model-output>
	Gridded Hydrologic Model Output provides gridded hydrologic projections for four watersheds in the province.	Interactive map with downloadable datasets	British Columbia (Four watersheds)	<https://www.pacificclimate.org/data/gridded-hydrologic-model-output>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Pacific Climate Impacts Consortium (continued)	PCIC's Climate Explorer visualizes future projections of climate conditions in the Pacific and Yukon regions based on GCM CMIP5 10-km-resolution downscaled data with a daily time resolution.	Interactive map, graphs, downloadable datasets	Pacific and Yukon regions (1961–2099)	<https://pacificclimate.org/analysis-tools/pcic-climate-explorer>
Fraser Basin Council	The Retooling for Climate Change website supports local governments in preparing for climate change adaptation.	Guidebooks, synthesis reports, and other informational material	British Columbia	<https://www.retooling.ca/>
University of British Columbia	Future Delta 2.0 is a serious videogame enabling real-time exploration of local climate change scenarios in local settings.	Educational videogame	British Columbia	<https://futuredelta2.ca/>
Government of Alberta	Surface Water Quality Data users can view and download water quality variables in lakes and rivers across the province.	Datasets and interactive map	Alberta	<https://www.alberta.ca/surface-water-quality-data.aspx>
	The Alberta River Basins Application is an interactive map showing a variety of near real-time water-related data.	Interactive map and downloadable datasets	Alberta	<https://rivers.alberta.ca/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Alberta (continue)	The Alberta Water Licence Viewer is an interactive web application that allows users to search for existing water licences.	Interactive map	Alberta	<http://waterlicences.alberta.ca/>
Saskatchewan Water Security Agency	The Lakes and Rivers website section provides near real-time stream flow, water levels and ten-day forecasts.	Hydrographs and streamflow data	Saskatchewan	<https://www.wsask.ca/Lakes-and-Rivers/>
	The Water Wells GIS Web application provides information on Water Wells in Saskatchewan, including information on local lithology, completion date, and well depth.	Interactive map with downloadable datasets	Saskatchewan	<https://gis.wsask.ca/Html5Viewer/index.html?viewer=WaterWells.WellsViewer/>
Government of Manitoba	The Manitoba Drought Monitor website provides hydrologic forecasts, reports, flood alerts and drought information.	Interactive map and downloadable datasets	Manitoba	<https://www.gov.mb.ca/water/drought_condition/>
	The Hydrologic Forecast Centre provides timely hydrologic forecasts, maps and information for lakes and rivers.	Data and interactive map	Manitoba	<https://gov.mb.ca/mit/floodinfo/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Ontario	Far North Major River Systems Maps provide stream and climate monitoring information.	Interactive map and downloadable datasets	Ontario	<https://geohub.lio.gov.on.ca/datasets/major-river-systems-in-the-far-north>
	Provincial (Stream) Water Quality Monitoring Network online map provides water chemistry data from sampling sites.	Interactive map and downloadable datasets	Ontario	<https://www.ontario.ca/environment-and-energy/map-provincial-stream-water-quality-monitoring-network>
	Baseline Hydrology Statistics provide data on streamflow regimes for Southwestern Hudson Bay and Nelson River watershed systems. Data includes frequency, timing, duration and discharge at Water Survey Canada gauge locations.	Datasets	Ontario, Southwestern Hudson Bay and Nelson River Watershed	<https://www.ontario.ca/data/baseline-hydrology-statistics>
	The Intensity-Duration-Frequency (IDF) Curve Lookup is a web-based application for retrieving rainfall IDF curves.	Datasets and online graphing	Ontario	<http://www.mto.gov.on.ca/IDF_Curves/terms.shtml>
Ontario Climate Consortium (OCC)	The OCC website provides high-quality and regionally specific climate information for decision makers.	Reports and other publications	Ontario	<https://climateconnections.ca/programs/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
International Institute for Sustainable Development (IISD)	IISD Experimental Lakes Area provides long-term ecosystem and atmospheric datasets—available by request. The metadata includes hydrology, physical limnology, zooplankton, fish, algae ecology, chemistry and meteorology research data.	Metadata	Northwestern Ontario (58 small lakes and their watersheds) (1968–present)	<https://www.iisd.org/ela/science-data/our-data/metadata/>
Government of Quebec	*Ministère de l'Environnement et de la Lutte contre les changements climatiques* provides hydrological and hydroclimatological forecasts, and historical data.	Datasets	Quebec	<https://www.cehq.gouv.qc.ca/prevision/index.asp>
	The Hydroclimatic Atlas of Southern Quebec describes the current and future water regime of southern Quebec.	Interactive map and datasets	Quebec	<https://www.cehq.gouv.qc.ca/hydrometrie/index.htm>
Government of New Brunswick	The River Watch and Flood Forecast tool provides 5-day flood forecasts and historical water level information.	Datasets	New Brunswick	<https://www2.gnb.ca/content/gnb/en/news/public_alerts/river_watch.html>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of New Brunswick (continued)	Coastal Erosion Data displays trends of coastal erosion and shoreline displacement based on specific measurement sites.	Datasets	New Brunswick	<http://www.snb.ca/geonb1/e/apps/apps-E.asp>
Government of Nova Scotia	The Flood Event Database contains historical records of flood events in Nova Scotia since 1992.	Interactive map	Nova Scotia (1992–Feb. 2015)	<https://mathstat.dal.ca/~ameliay/flood/>
	The DNR Coastal Flood Risk Map provides static coastal flood risk maps, and emergency coastal flooding decision-support systems for different regions of the province.	Interactive map	Nova Scotia	<https://agrgims.cogs.nscc.ca/CoastalFlooding/lidar-mapping>
	The Potential Impact of Drought to Private Wells gridded interactive map shows potential water shortages and drought risk.	Interactive map	Nova Scotia	<https://fletcher.novascotia.ca/DNRViewer/?viewer=DroughtIndex>
Nova Scotia Community College	The Applied Geomatics Research Group Coastal Storm Surge Interactive Map is a Decision Support System for flood risk from storm surges and sea-level rise.	Interactive map and data	Nova Scotia	<http://agrgims.cogs.nscc.ca/CoastalFlooding/Map/>

ORGANIZATION	RESOURCE DESCRIPTION	DATA TYPE	SCALE	LINK
Government of Prince Edward Island	The Surface Water Quality Database provides information about sampling locations, downloadable data and visualizations.	Datasets and visualization tools	Prince Edward Island	<https://www.princeedwardisland.ca/en/service/view-surface-water-quality>
Government of Newfoundland and Labrador	The interactive Geoscience Atlas allows users to select and view layers that include coastal monitoring variables.	Datasets and mapping tools	Newfoundland and Labrador	<https://gis.geosurv.gov.nl.ca/>
Atlantic Climate Adaptation Solutions Association	The Coastal Community Adaptation Tool supports decision making around coastal flooding and erosion.	Reports and case studies	Atlantic Canada	<https://atlanticadaptation.ca/en/content/guidance-coastal-flooding-and-erosion-adaptation>
U.S. National Snow and Ice Data Center	The Ice Climatology dataset contains long-term information on ice conditions over specific geographic regions.	Datasets	Arctic/Antarctic	<https://nsidc.org/data/sipn/data-sets.html>

This list is not exhaustive and URLs may change over time.

To help address this issue and enhance collaboration around information sharing at the national level, the Canadian Centre for Climate Services (CCCS) was established by Environment and Climate Change Canada in 2018. The goal of the CCCS is to provide authoritative, relevant and timely climate change information and assistance interpreting this information. The Centre indirectly plays an important role in centralizing resources related to climate change and water resources spread across many organizations. It complements work undertaken by others, such as Canada's Regional Adaptation Collaboratives (RACs), which produced a variety of vulnerability assessments, guidebooks and technical studies, and significantly increased awareness of climate-related issues, resulting in a number of outputs to address the water-related risks of climate change (Eyzaguirre, 2015).

Despite these efforts, there are key gaps in Canadian water information systems, and these present challenges to adaptation in the water sector, including:

- Fewer weather and hydrometric monitoring stations in northern regions and watersheds (Koshida et al., 2015);
- Limited data availability for groundwater, water quality, evapotranspiration, return flows, glaciers, future trends and actual water use (Bakker and Cook, 2011; Corkal et al., 2011; Sandford et al., 2011; National Round Table on the Environment and the Economy, 2010; Stratton, 2005; Langsdale et al., 2004), ecological health (World Wildlife Fund, 2017), and water-related infrastructure (Canadian Council of Professional Engineers, 2008);
- Uneven regional research on hydrological trends. Current research is focused on northern regions, British Columbia and the Prairie region, with fewer studies in Eastern Canada. Drought analysis and climatological trend research is primarily focused on the Prairie region (Mortsch et al., 2015);
- Limited understanding of spatial and temporal variability in climate change impacts on water resources (Shrestha, et al., 2012);
- Uncertainty associated with hydrologic modelling tools, data inputs and methodologies for generating future projections (Milner et al., 2018; Cohen et al., 2015; Brown and Wilby, 2012; Poulin et al., 2011);
- Little standardization, centralization and consistency in data collection, indicators and methodologies for risk assessments (Moody and Brown, 2012) and water availability studies (Koshida et al., 2015; Dunn and Bakker, 2011); and
- Stakeholder uncertainty about what data exists, how it can be accessed and integrated into planning, and who is responsible for collecting and assembling data (Canadian Water Network, 2019; Ontario Centre for Climate Impacts and Adaptation Resources, 2011; Telfer and Droitsch, 2011; Diaz et al., 2009).

These limitations result in uneven information system capacity to build resilient and adaptive institutions and infrastructure.

4.6.3 Water-related infrastructure

Infrastructure provides critical services for Canadians. For example, dams provide flood control, water supply, and hydroelectric production; wastewater infrastructure removes harmful nutrients and toxins from effluent to meet health and environmental standards; and pumping stations deliver water to industries, communities and households. There is also a growing understanding that natural infrastructure, such as wetlands, forests and soils, provides outcomes similar to built infrastructure at a lower cost and more efficiently (Moudrak et. al, 2018), largely resulting from reduced maintenance and life-cycle management costs.

Water-related climate change impacts constitute some of the main hazards to all infrastructure in Canada (Public Safety Canada, 2018) and can manifest as physical damage, service disruptions, and increased maintenance and operational costs (Boyle et al., 2013). Ageing infrastructure is particularly vulnerable to climate change impacts (Public Safety Canada, 2018).

Three assessments provide a general overview of water-related climate change hazards, infrastructure vulnerabilities and adaptive actions across Canada (Andrey et al., 2014; Boyle et al., 2013; Canadian Council of Professional Engineers, 2008). While extensive vulnerability assessments have been undertaken at the local and regional levels, there is much less information available at the provincial and national scales (Boyle et al., 2013). Insufficient information is the main factor limiting a systematic pan-Canadian assessment of water infrastructure (Andrey et al., 2014); however, key hazards and risks to water infrastructure are identified in the assessments listed above and are summarized in Figure 4.10.

A key tool for assessing the vulnerability of water resource infrastructure in Canada is the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol (*see* Box 4.3).

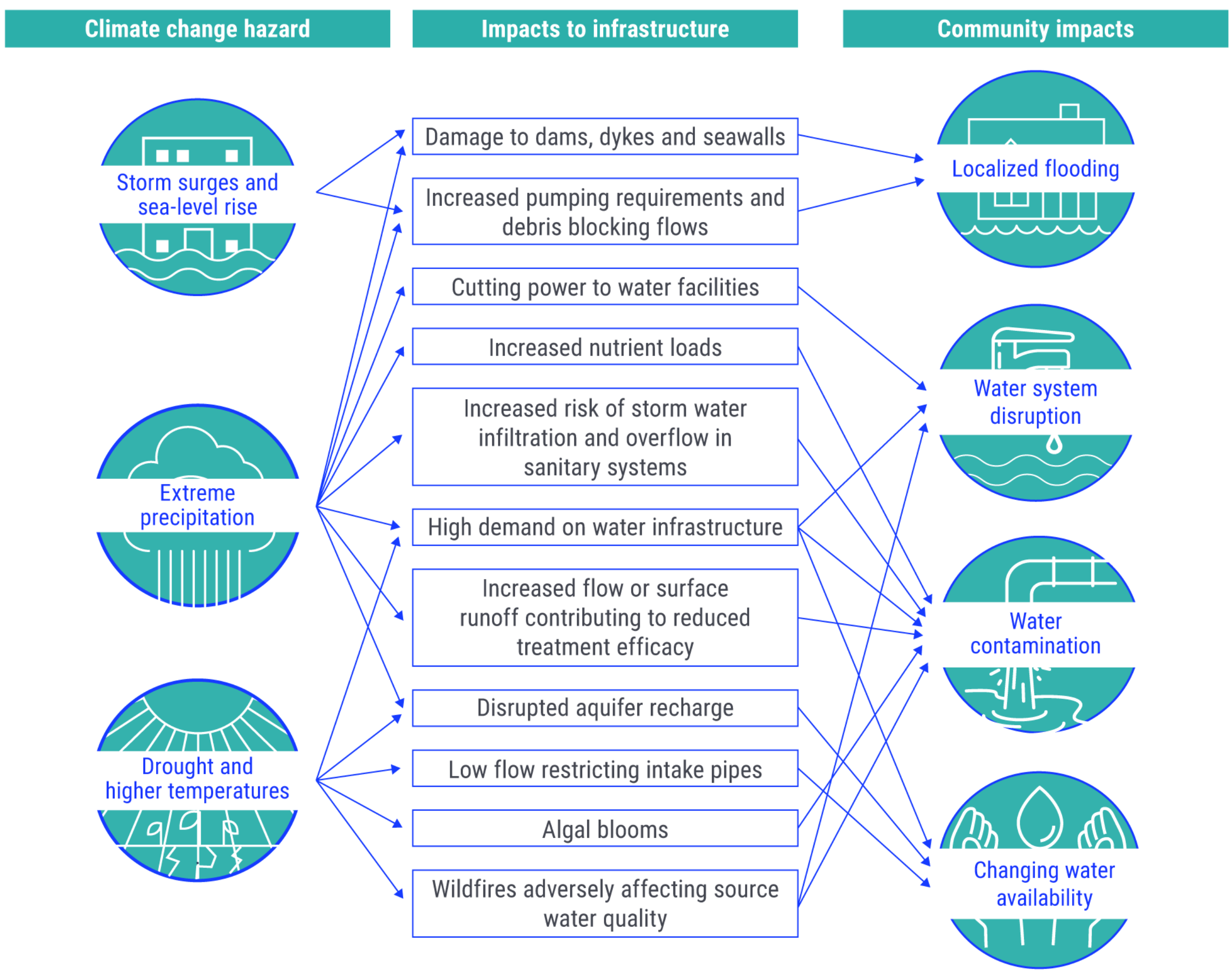

Figure 4.10: Key climate change hazards and risks to water infrastructure.

Box 4.3: Assessing infrastructure vulnerability

The Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol is a five-step procedure to systematically assess engineering vulnerability and risk from current and future climate impacts; this procedure can be applied to any type of infrastructure. The five steps include 1) project definition, 2) data gathering, 3) vulnerability assessment (*see* Figure 4.11), 4) vulnerability indicator analysis, and 5) recommendations for building in resilience.

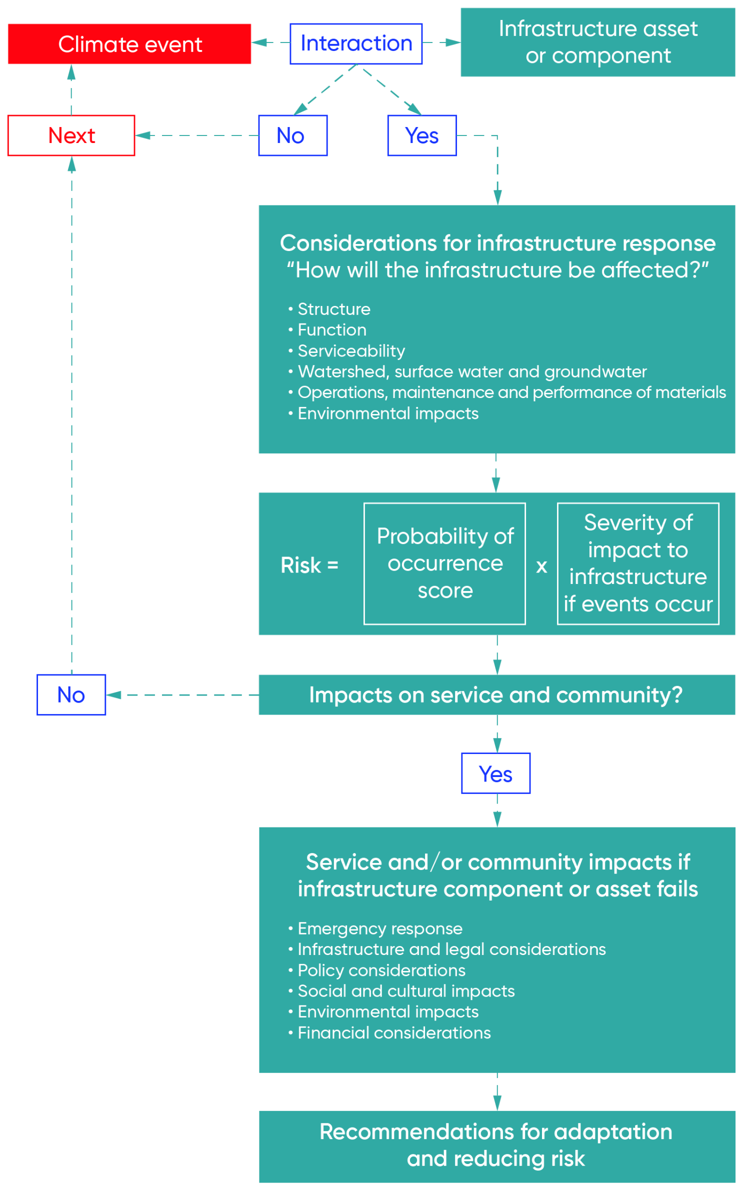

Figure 4.11: Flow chart illustrating step 3 of the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol. Step 3 includes a vulnerability assessment to identify the relationships between climate change and impacts to infrastructure. Source: Adapted from Félio, 2017.

The PIEVC protocol has been applied in dozens of local water infrastructure assessments, leading to a wide range of conclusions and recommendations. For example, the City of Calgary concluded that its water supply infrastructure is generally resilient to climate change impacts (Associated Engineering, 2011), while the City of Nelson found that storm water infrastructure required additional investment to alleviate flooding concerns (*see* Case Story 4.7; Paré, 2014). In general, case study findings point to best practices for resilient water infrastructure design and operation, including:

- good maintenance and management; older and/or poorly maintained and managed infrastructure is more at risk to climate impacts;
- building redundancies into water systems (e.g., multiple intake points and delivery mechanisms);
- for new infrastructure, considering climate change impacts during project design to avoid difficult and costly retrofits or facility upgrades once built; and
- ensuring infrastructure-related codes, standards and related instruments (CSRI) reflect reliable and up-to-date information and/or factor in climate change projections.

These assessments also call attention to three major vulnerabilities in existing water infrastructure systems. Firstly, these systems usually assume that conditions of the past will apply in the future, with design and operating rules based on empirical records from the past rather than anticipated future conditions (Sauchyn et al., 2016; Mguni, 2015; Boyle et al., 2013; Hamlet, 2011; de Loë and Plummer, 2010; Minville et al., 2010). As it is not always clear what climate information was used to develop codes, standards or related instruments, developing future standards is not always as simple as updating past climate data (Andrey et al., 2014). Secondly, there is a tendency to not account for low-probability climate events that have highly adverse impacts (Sauchyn et al., 2016). Case studies highlight the importance of robust emergency planning and preparedness, as well as back-up power and communications systems, to support infrastructure design and maintenance (Félio, 2015; Nodelcorp Consulting, 2014). Thirdly, there are significant costs associated with infrastructure maintenance, redundancies, upgrades and increasingly stringent regulations (de Loë and Plummer, 2010). The most recent Canadian Infrastructure Report Cards (2019, 2016) indicate that while the majority of potable water, wastewater and storm water systems are rated "good," reinvestment rates in these systems remain below the rates required to maintain or improve them (Canadian Infrastructure Report Card, 2019, 2016).

Requirements around design, building and operations are changing to address these vulnerabilities. For example, Infrastructure Canada introduced a "climate lens" assessment requirement for several of its funding initiatives in 2018. The assessment requires proponents to consider risk management approaches to adapt to climate change-related impacts during the lifecycle of the proposed infrastructure and potential upstream and downstream impacts (e.g., reduction of downstream flooding due to engineered wetland construction) (Infrastructure Canada, 2018).

Case Story 4.7: Climate change impacts on water and wastewater infrastructure at Akwesasne

In 2015, Engineers Canada initiated discussions with the Ontario First Nations Technical Services Corporation about the impacts of climate change on infrastructure in Indigenous communities. The intent was to incorporate climate considerations into First Nations asset management planning.

Engineers Canada's PIEVC Protocol was considered the best approach to assess climate risks for infrastructure, and work progressed in the Mohawk territory of Akwesasne. Akwesasne is a community of approximately 12,300 people distributed across three districts: Kawehno:ke (Cornwall Island, Ontario), Kana:takon (Saint Regis, Quebec) and Tsi:Snaihne (Snye, Quebec). The Akwesasne territory spans portions of Ontario, Quebec and New York, and is governed by the Mohawk Council of Akwesasne and the Saint Regis Mohawk Tribe.

The first phase of the study (Félio, 2017) employed the PIEVC protocol to evaluate the vulnerability to climate change impacts in potable water and wastewater collection and treatment systems for Cornwall Island, Saint Regis and Snye. Risks were ranked based on occurrence probability and severity, but included special cases such as low probability–high impact events. The team analyzed climate–infrastructure interactions that would impact infrastructure design, functionality, serviceability and community impacts, such as social and cultural effects and emergency response.

The risks assessed differed between the locations and systems evaluated, but largely included water-related climate change impacts such as ice storms, hail, snowfall and rain events, as well as tornadoes and strong winds. Of these, the hazard–infrastructure interactions considered to pose "high" and "extreme" risks are projected to increase in the future (by the 2050s).

The study found that the water and wastewater infrastructure of Akwesasne appears to be in good condition to withstand some increases in frequency and intensity of the climate events predicted, with the caveat that deteriorating infrastructure will present a greater risk (Félio, 2017). Recommended adaptive and risk mitigation measures include maintaining high levels of operations staff, competencies and infrastructure conditions; reviewing land-use policies to avoid building in high-risk areas of the community; and emergency planning, such as implementing a weather alert system with public outreach (Félio, 2017).

The second phase of this study led to the development of a PIEVC Protocol tailored to First Nations communities. This version of the protocol provides guidance on how to integrate traditional ecological knowledge (TEK); it is adapted to unique circumstances that impact Indigenous communities (e.g., smaller communities, remote locations, etc.) (Engineers Canada, 2018).

There is also greater awareness of the potential of nature-based solutions or natural infrastructure to reduce the water-related impacts of climate change (Stanley et al., 2019; Moudrak et al., 2018). Natural infrastructure is defined as "a strategically planned and managed network of natural lands, such as forests and wetlands, working landscapes, and other open spaces that conserves or enhances ecosystem values and functions, and that provides associated benefits to human populations" (Benedict and McMahon, 2006). This infrastructure can be fully natural (e.g., conserved natural wetland) or engineered (e.g., restored wetland with an engineered outlet), and can complement existing built infrastructure (Moudrak et al., 2018). In water resource management, natural infrastructure tends to be more flexible than built infrastructure and provides important co-benefits, such as carbon sequestration and improved water quality and ecosystem health (*see* Ecosystem Services chapter; Goldstein et al., 2019; Stanley et al., 2019; Moudrak et al., 2018). Widespread implementation of natural infrastructure solutions has been hindered by a lack of knowledge and expertise, and policy and regulatory processes that favour built infrastructure (ICF, 2018). However, a number of recent examples across Canada have illustrated natural infrastructure success stories for reducing the water-related impacts of climate change (*see* Box 4.4).

Box 4.4: Nature-based options for adaptation

Floodplain preservation, wetland restoration, flood setbacks, two-stage channels (for high and low flows), relief channels (for high flows) and adding in-stream structures and bank vegetation are all nature-based strategies that reduce the risks from riverine flooding (ICF, 2018). These solutions are effective methods of enhancing the capacity of water systems to absorb the impacts of excess water. For example, a study demonstrated that naturally occurring wetlands in Ontario reduced flood damage costs to buildings by $3.5 million at a rural site and by $51.1 million at an urban site, while another study found a restored and engineered wetland in Manitoba provided flood reduction, water quality and other benefits valued at $3.7 million (Moudrak et al., 2018). In urban centres, runoff from rainfall can contribute to urban flooding and increase contaminant loads to receiving waters. Nature-based adaptation options such as green roofs, bioswales (sloped, vegetated surfaces), bioretention ponds, rain gardens, urban trees and vegetative swales are effectively reducing the risks from storm water runoff in many sites across Canada (*see* Cities and Towns chapter; ICF, 2018). For example, Toronto's Green Roof Program contributes to an estimated reduction of just over 12,000 m^3 (435,000 ft^3) of storm water annually, and enabled the creation of over 100 jobs related to the design, manufacturing, installation and maintenance of the infrastructure (ICF, 2018). Similarly, naturally occurring ponds in Gibsons, B.C., provide approximately $4 million of storm water storage services annually (Moudrak et al., 2018).

The vulnerability assessment process has helped water resource managers across Canada envision how climate change interacts with current systems to exacerbate existing risks or produce new ones. This process, in turn, is helping to identify adaptation actions, and ultimately guide planning and resource allocation in the face of uncertainty.

4.7 Moving forward

4.7.1 Knowledge gaps and research needs

This chapter highlights some key knowledge and information exchange gaps that present challenges for adaptive water resources management efforts in Canada. These include:

- **Access to data:** While there is a plethora of water and climate information and research actively produced at many scales and locations across Canada, there is considerable variation between this data, with little centralization or standardization (Dunn and Bakker, 2011). This contributes to uncertainty around what data exists, and how it can be accessed and interpreted or applied (Telfer and Droitsch, 2011; Diaz et al., 2009).
- **Guidance for decision making:** There is a critical need for translating scientific and technical knowledge into practical guidance for decision makers, managers, practitioners and stakeholders. This includes guidance for considering climate change in engineering design, codes and standards for built and natural infrastructure, and in policy and institutional mandates (IJC, 2018; de Loë, 2017; Andrey et al., 2014; Nodelcorp Consulting, 2014; Canadian Council of Professional Engineers, 2008).
- **Engagement for shared understanding:** Stakeholder engagement is critical to advancing adaptation in the Canadian water sector. The development of strategies to build consensus or compromise around solutions between the conflicting needs and objectives of water stakeholder groups is an emerging field of practice and study in the Canadian water sector. There is a need for practical and effective methods to assist decision makers in navigating stakeholder interactions, negotiating conflicts, accounting for changing social dynamics, and reconciling trade-offs between competing water uses (Global Water Futures, 2020; Clark et al., 2016; Hurlbert and Diaz, 2013; Hamlet, 2011; Ivey et al., 2004).
- **Knowledge mobilization between knowledge producers and users:** Effective knowledge mobilization is required to bridge the gap between knowledge generated by the research community and water organizations, and knowledge held by water practitioners and stakeholders across Canada. Knowledge mobilization is a reciprocal exchange and uptake of knowledge between organizations and individuals dedicated to making research useful to society (Research Impact Canada, 2018). Social factors play a significant role in the uptake of new knowledge, and it is important to develop strong, trusting, meaningful relationships between researchers and knowledge user communities (Crona and Parker, 2011).

Addressing the following additional research needs and knowledge gaps would help to better understand the effectiveness of adaptation efforts and advance adaptive management processes:

- **Monitoring and data collection:** There is limited monitoring capacity, particularly in northern regions, and a need for additional observational data for groundwater, water quality, evapotranspiration, return flows, glaciers and actual water use (Koshida et al., 2015; Bakker and Cook, 2011; Corkal et al., 2011; Sandford et al., 2011; National Round Table on the Environment and the Economy, 2010; Stratton, 2005; Langsdale et al., 2004).

- **Modelling, forecasting and prediction:** Detailed model inter-comparison studies would provide insights about shortcomings in specific models and multi-model analyses (Milner et al., 2018; Cohen et al., 2015; Brown and Wilby, 2012; Poulin et al., 2011). Such studies would allow world-class hydrology and water quality prediction models to be deployed nationally for short-term forecasting and long-term prediction of changes to water availability and quality. Practical methods to clarify, reduce or prioritize key areas of model uncertainty need to be developed with the practitioner community and effectively mobilized in the Canadian water sector (Clark et al., 2016; Razavi and Gupta, 2016; Brown and Wilby, 2012).
- **Understanding of institutional barriers:** Institutional barriers to adaptation are under-studied, and not always comprehensively understood, despite their recognition as a real issue by Canadian water practitioners (Global Water Futures, 2020; Straith et al., 2014). There is an on-going need to look beyond the science and technology of climate change to drive governance change that will enhance the climate resilience of Canadian water systems (Gober, 2013; de Loë and Plummer, 2010). While the importance to adaptive governance is broadly recognized, indicators of institutional resilience are rarely reflected in vulnerability tools, and there is a limited understanding of how to adequately capture and measure these concepts (Plummer et al., 2012).
- **Documentation of successes and failures:** Evaluation of adaptive management processes is critical; however, it often lacks rigorous documentation in academic literature. Evaluation is necessary at local, regional and national scales, including monitoring of short-term and longer-term outcomes from adaptation measures. Identifying and sharing failures, while often avoided, is sometimes more useful for informing adaptation efforts and social learning.

4.8 Conclusion

Water is central to economic growth, environmental health and social stability in Canada. This chapter has shown that water systems are in the throes of rapid transformation as a result of climate change and human action. Global climate change has already affected Canada's cold-dominated water cycle, melting ice and snow, altering the precipitation phase, and changing the nature and timing of water-related natural hazards. Future changes are uncertain, but include the following: risks of reduced water availability and more frequent drought, particularly in the southern Prairies and interior of British Columbia; extreme rainfall contributing to floods; and additional occurrences of harmful algae blooms.

There is much to be done to prepare Canada for an uncertain water future. Uncertainty is not an invitation to inaction; it does, however, change the way in which we must prepare. Canadian water institutions have historically been organized to deal with predictable future conditions where we can extrapolate a future based on the past. Climatic uncertainty has changed that. Water organizations are beginning to embrace exploratory modelling, scenario exercises and adaptive management as a way of planning under uncertainty and of adjusting plans to meet changing circumstances.

Responsibility for adaptation in the water resources sector is also spread across a complex array of governments and organizations involved in water stewardship activities. Effective coordination between these groups plays an important role in strengthening adaptation in the water resources sector, and is exemplified by transboundary water organizations in Canada. Case studies also emphasize that adaptation is a local, place-based process. While access to technical skills, resources and contextual, place-based knowledge are assets to adaptation, capacity challenges are often concentrated in rural, northern and Indigenous communities. These communities are often the most vulnerable to the water-related risks of climate change, and bear a disproportionate burden of the costs of adaptation.

Canadians experience climate change impacts in their own communities, and climate-related impacts vary significantly across Canada. Water practitioners benefit from access to high quality, locally relevant climate data to reduce vulnerabilities in systems and infrastructure, and Canadians are more likely to support adaptation efforts when they understand co-benefits and are armed with information to act decisively. One-size-fits-all national adaptation strategies are unlikely to meet the challenge of climate change or the values of Canadians across regions.

Still, adaptation efforts lag behind what will be required to meet the challenges of climatic change. They are for the most part one-off experiments at local levels rather than part of institutionalized processes for environmental management and societal change. Water-related risks have not yet reached critical urgency in the minds of Canadians to trigger support for widespread, immediate action.

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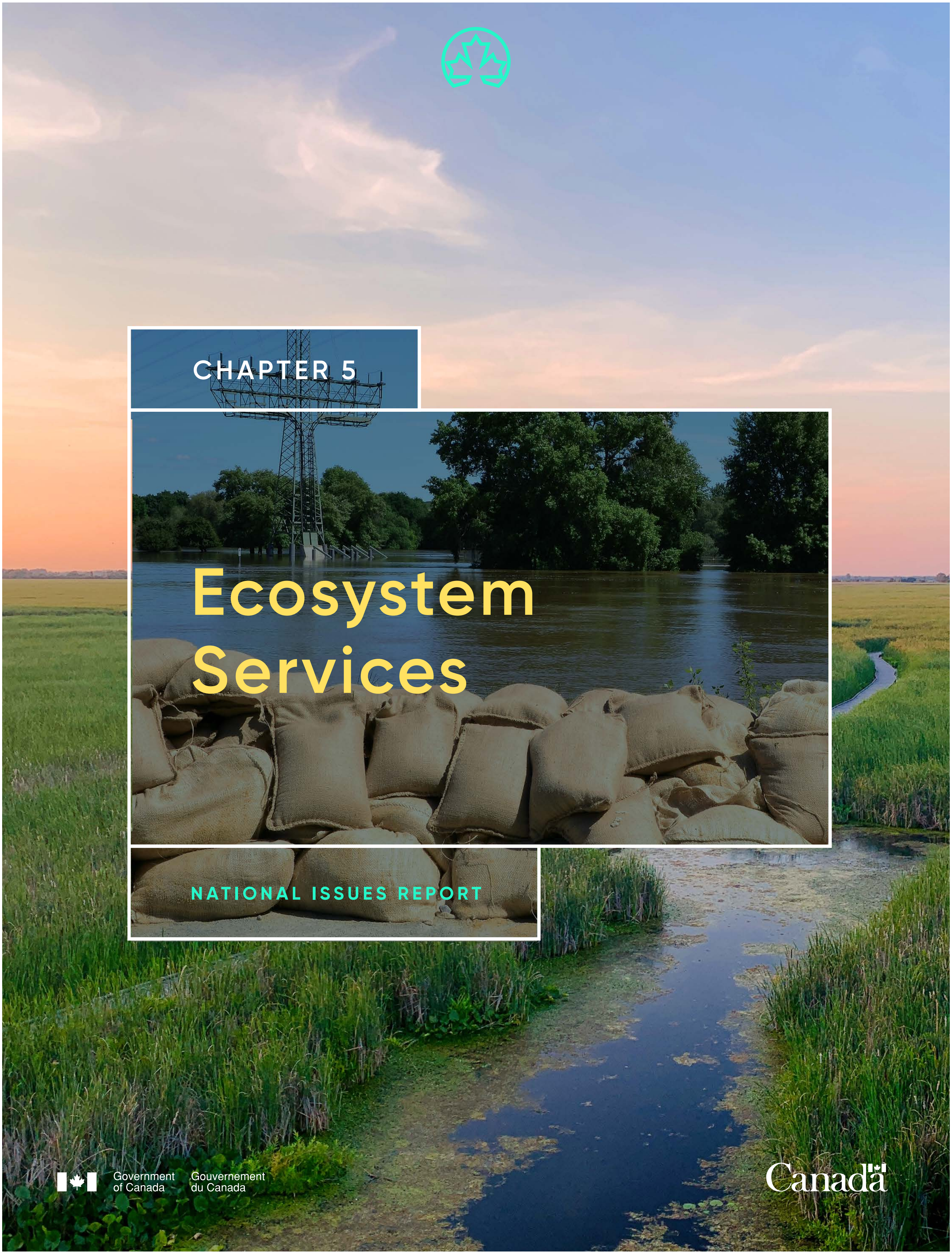

CHAPTER 5

Ecosystem Services

NATIONAL ISSUES REPORT

Government of Canada Gouvernement du Canada

Canada

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Key messages

Climate change is threatening Canada's ecosystems and the services they provide (*see* Section 5.2)

Climate change is already affecting the capacity of Canada's ecosystems to provide services. Extreme weather events, in particular, and shifts in seasonal climate patterns are interacting with other pressures on ecosystems causing a range of impacts. These will continue to intensify.

Impacts will vary across Canada's ecosystems and regions (*see* Section 5.3)

Ecosystem responses to climate change across Canada's regions will vary. Northern, mountainous and coastal regions are especially vulnerable to climate change impacts on ecosystem services, due in large part to limited adaptation options. Strengthening the adaptive capacity of people and communities living in these regions is vital to maintaining ecosystem services.

Indigenous Knowledge is vital to maintaining ecosystems (*see* Section 5.4)

Indigenous Knowledge is critical for maintaining ecosystems and the services they provide in a changing climate. Indigenous Knowledge Systems encompass different perspectives for understanding environmental complexity, and provide strategies to reduce, manage and adapt to environmental change in a place-based and holistic manner.

Nature-based approaches to adaptation maximize benefits (*see* Section 5.5)

Nature-based approaches to adaptation reduce climate change risks to communities, and are often cost-effective and flexible compared with engineered alternatives. They also deliver a wide range of social, environmental and economic co-benefits, and help to strengthen the adaptive capacity of communities.

5.1 Introduction

Ecosystems play an important role in supporting society through the goods and services they provide, such as food, clean water, air purification and climate regulation. They also contribute to climate change mitigation, by sequestering carbon from the atmosphere. The services provided by ecosystems are impacted by multiple factors, including land-use change and overexploitation, which can reduce their capacity to deliver benefits in the short and long term. As the climate continues to change and ecosystems shift in response to changing environmental conditions, their capacity to provide these services will be affected. Maintaining, restoring and managing ecosystems to address climatic and non-climatic stressors are key strategies for reducing their vulnerability in the face of climate change, by enhancing their resilience to changing conditions. Considering the important connections between Indigenous communities and nature, Indigenous Knowledge is vital to understanding how climate change is affecting ecosystems and to the design and implementation of approaches for their preservation and management.

Ecosystems also play an important buffering role in reducing the severity of climate change impacts on society, including through services such as flood attenuation and storm surge protection. Increasingly, nature-based approaches to climate change adaptation are being explored and adopted at different levels as lower-cost measures (in comparison to engineered approaches) for reducing climate change risks, while also delivering a range of social and economic co-benefits.

5.1.1 Chapter scope and structure

This chapter explores the risks and complex impacts that climate change poses for Canada's ecosystems and the services they provide, as well as opportunities for adapting to climate change. It begins by presenting an overview of key concepts, definitions and considerations. The chapter then discusses the diverse ways in which climate change is currently affecting and is anticipated to affect ecosystems and their services in the future, with examples pertaining to different types of ecosystems and in various regions across the country. The chapter also discusses the role of Indigenous Knowledge in understanding and responding to climate change impacts to ecosystems. The chapter then addresses the growing role and rapidly evolving recognition of nature-based approaches to adaptation for reducing climate change impacts to society. Case stories are included throughout the chapter to provide practical, on-the-ground examples of adaptation in this field.

The chapter focuses on four key messages, which highlight the current state of knowledge on issues of priority. As such, it does not provide a comprehensive summary of climate change impacts and adaptation considerations across all regions, ecosystems and social groups. The author team recognizes that many knowledge gaps remain and that there are a number of emerging issues related to this topic, which are discussed towards the end of the chapter.

This chapter builds from the Biodiversity and Protected Areas chapter of Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation (Nantel et al., 2014). It is, however, the first chapter within Canada's national knowledge assessment process to examine ecosystem services and nature-based approaches to adaptation. As such, it is intended to serve as an initial input into the rich and rapidly-evolving dialogue around this topic. Future assessments will build from this chapter and endeavour to capture and reflect the learning and new knowledge that is being generated through the multitude of projects and research currently underway in this area.

5.1.2 Canadian context

Canada is home to a wide range of ecosystems, which deliver extensive services to society. The Canadian Council on Ecological Areas (2014) defines 18 terrestrial ecozones, 12 marine ecozones and one freshwater ecozone for the country, where an "ecozone" is the broadest level of ecological classification used in Canada (*see* Figure 5.1).

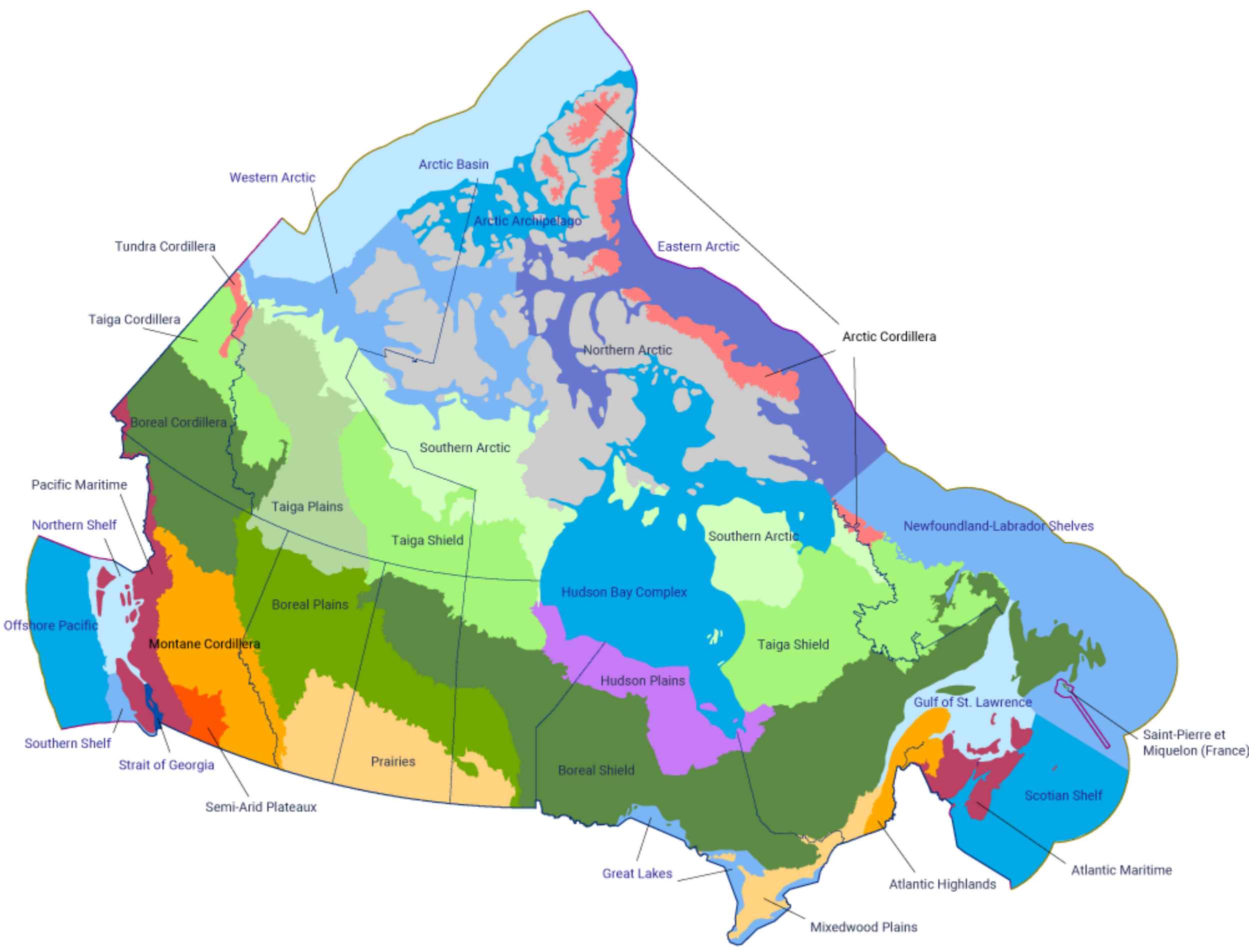


Figure 5.1: Map of Canada's terrestrial and marine ecozones. Source: Adapted from Canadian Council on Ecological Areas, 2014.

Canadians derive indispensable benefits from ecosystem services, which contribute to culture, economies, jobs, health and other dimensions of human well-being. The economic value of ecosystem services in Canada is estimated to be at least $3.6 trillion per year (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2018), which was more than double the nation's GDP in 2018. Canada is recognized as one of five countries that, together, host 70% of the world's remaining untouched wilderness areas (Watson et al., 2018), and is considered to hold a greater capacity to supply ecosystem services than the global average (IPBES, 2018). An estimated 285.8 million tonnes of biomass—agricultural crops, livestock and poultry, milk, maple products, honey, forestry and fisheries—were extracted for human use in 2010 from Canada's terrestrial and aquatic ecosystems (Statistics Canada, 2013). While Canada overall scores highly on the new Biodiversity and Ecosystem Services Index developed by Swiss Re Institute (2020), ecosystems in some parts of the country may be in decline, with resulting impacts to ecosystem services (*see* Box 5.1).

Box 5.1: The Swiss Re Institute's Biodiversity and Ecosystem Services Index

Recognizing nature's important contributions to quality of life and the economy, the Swiss Re Institute recently launched a Biodiversity and Ecosystem Services (BES) Index[1], which aggregates data from across ten different categories—including habitat intactness, local air quality and climate regulation, erosion control and coastal protection—at a resolution of 1 km² (*see* Figure 5.2). This approach allows for a localized analysis of ten categories of biodiversity and ecosystem services, as well as assessments at the countrywide and regional levels. The index is also helpful for highlighting connections between BES and economic sectors (Gray, 2020).

1 Patent pending.

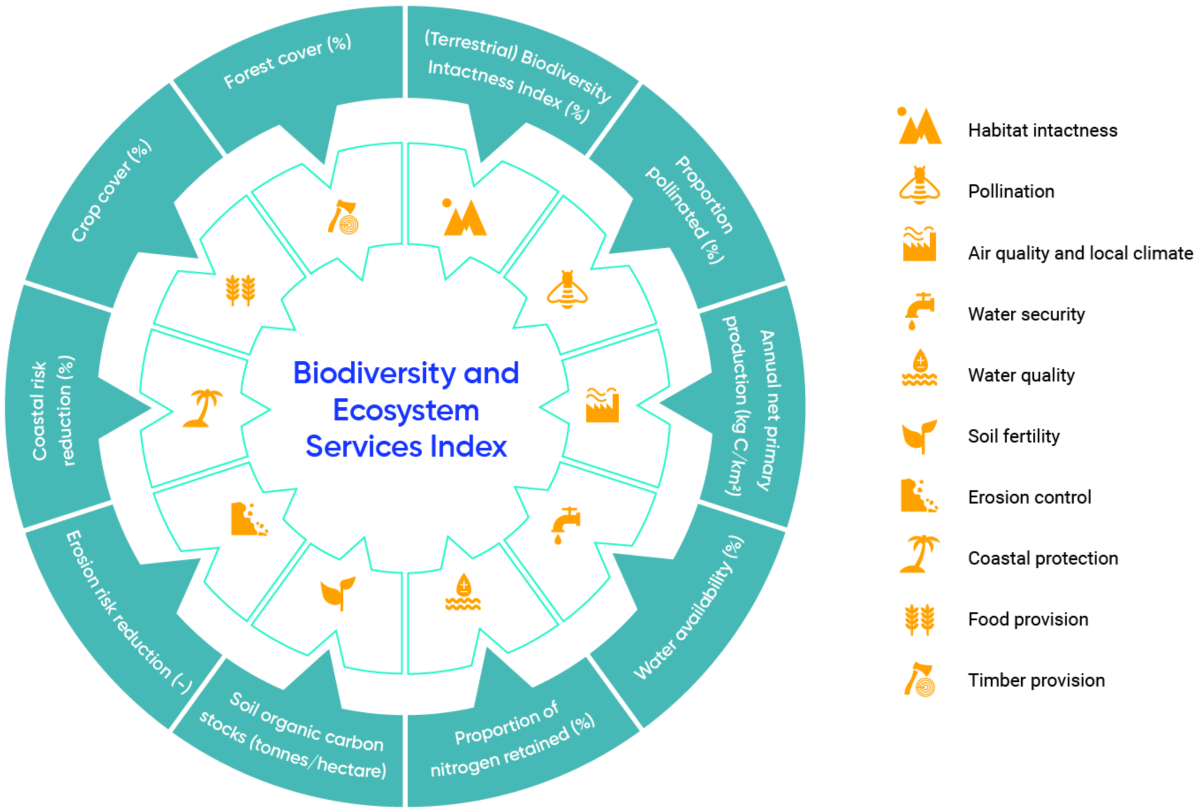


Figure 5.2: Ten categories that are considered within the new Biodiversity and Ecosystem Services Index developed by Swiss Re, which allows for country-wide or regional assessments of the state of biodiversity and ecosystem services. Source: Adapted from Gray, 2020.

Swiss Re considers locations with high BES Index values (i.e., in the upper 15th percentile globally) to be "intact" ecosystems, with high capacity to provide ecosystem services. In contrast, locations with low BES Index values (i.e., in the lower 15th percentile globally) are considered to be "fragile" ecosystems, whose capacity to deliver services has been comparatively compromised due to biodiversity loss and ecosystem degradation. Although Canada has a very high BES Index value overall, some areas within the country score very low (*see* Figure 5.3; Retsa et al., 2020).

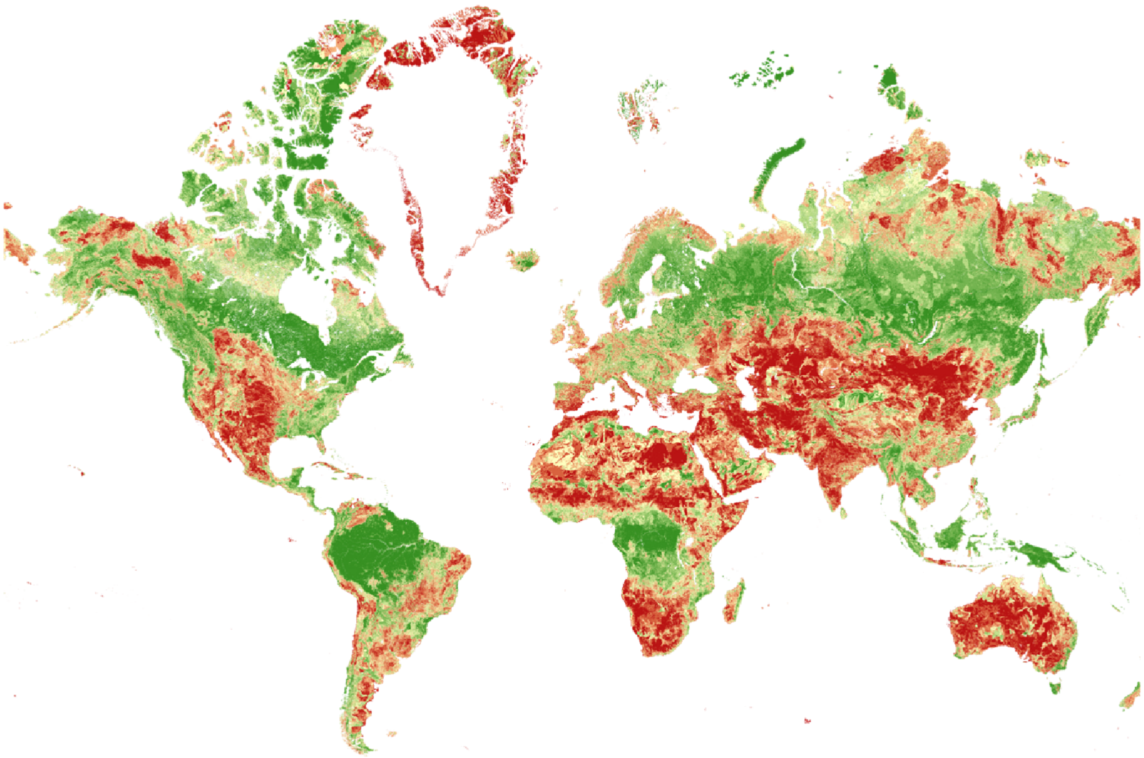


Figure 5.3: Map indicating Biodiversity and Ecosystem Services Index values for different parts of the world. Source: Adapted from Gray, 2020.

The BES Index can help to guide decision making on the use of natural assets for making businesses and investments more resilient to climate change impacts by assessing the state of biodiversity and ecosystem services, as well as the dependence of economic activity on these services (Retsa et al., 2020). The BES Index can also be helpful for informing government decision making on efforts to restore and preserve ecosystems, thereby safeguarding the services they provide.

The preservation of ecosystem services in the face of climate change and the application of nature-based approaches to climate change adaptation, as discussed throughout this chapter, may be a strategy to help achieve multiple goals. For instance, Canada has made a range of climate- and ecosystem-related commitments as a signatory to the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, the UN Sustainable Development Goals and the Paris Agreement, is also a participant and supporter of the Global Commission on Adaptation, and is co-leading the Nature-based Solutions Action Track with Mexico. Reporting on progress made towards these commitments is a federal requirement and can be a leverage point for mobilizing coordinated efforts across government agencies and non-government organizations that are working to reach similar goals.

5.1.3 Ecosystems, ecosystem services and biodiversity

Ecosystems are a dynamic complex, composed of living organisms—plants, animals and micro-organisms—and their environment, which interact in a multitude of ways as a functional unit (Minister of Supply and Services Canada, 1995). Biological diversity, also known as biodiversity, refers to the variability among living organisms—including those living in terrestrial, marine and other aquatic ecosystems—as well as the ecological complexes of which they are part; this includes diversity within and between species, as well as diversity across ecosystems (Convention on Biological Diversity, 1992). Nantel et al. (2014) provide an overview of climate change impacts on biodiversity in Canada.

Biodiversity and ecosystems produce a rich assortment of benefits that people depend upon and value, which are often referred to as "ecosystem services" (Millennium Ecosystem Assessment, 2005) or "nature's contributions to people" (IPBES, 2018). Examples of ecosystem services include climate regulation, regulation of freshwater and coastal water quality, carbon sequestration (*see* Box 5.2), and regulation of hazards and extreme events (*see* Table 5.1; IPBES, 2018). While ecosystem services and biodiversity are related, they are distinct concepts. For instance, managing ecosystem services can sometimes result in positive outcomes for biodiversity (e.g., promoting regulating services such as erosion control can positively influence biodiversity by safeguarding habitat), whereas other management actions can have negative repercussions for biodiversity (e.g., the selection of tree species based solely on optimizing carbon sequestration, which can lead to changes within an ecosystem that negatively affects biodiversity).

Ecosystem services are generated through an ecosystem's organization and structure, as well as through ecological processes and functions (*see* Figure 5.4). Ecological processes refer to any change or reaction (physical, chemical or biological) that occurs within an ecosystem, such as decomposition and nutrient cycling (Millennium Ecosystem Assessment, 2005). Ecosystem functions—a subset of the interactions between biophysical structures, biodiversity and ecosystem processes—represent the potential or capacity of an ecosystem to deliver services (TEEB, 2010). For example, wetlands (an ecosystem structure) offer a form of regulation (an ecosystem function) that helps to limit the negative impacts of flooding or extreme weather events on nearby communities (an ecosystem service) (de Groot et al., 2010a).

Ecosystem services can be classified in different ways, but for the purposes of this chapter, three categories are used: 1) regulating contributions (i.e., functional and structural aspects of organisms and ecosystems that may modify environmental conditions as experienced by people or that sustain or regulate material and non-material benefits); 2) material contributions (i.e., substances, objects or other material elements taken from nature that help to sustain people's physical existence and infrastructure, and that are typically consumed or consciously perceived); and 3) non-material contributions (i.e., services that affect people's subjective or psychological quality of life, individually and collectively) (*see* Table 5.1; IPBES, 2018).

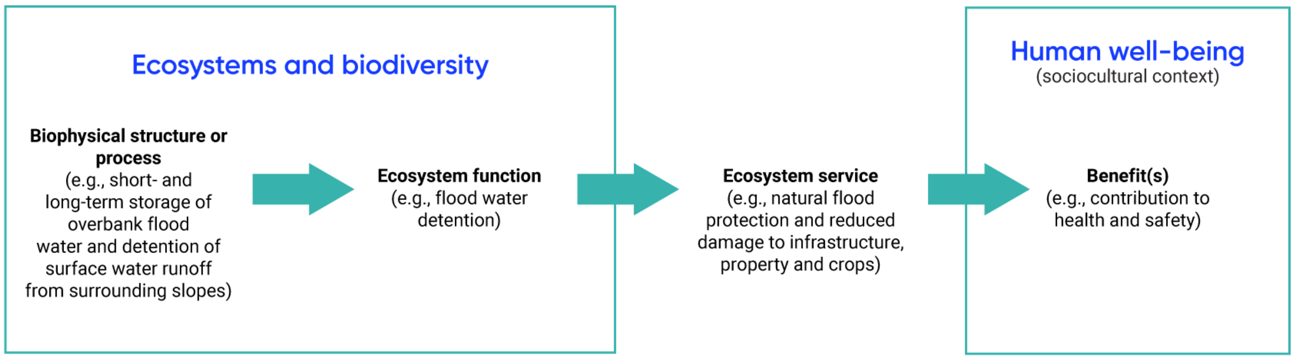


Figure 5.4: The interdependencies of ecosystems, biodiversity, biophysical process, ecosystem function and service, and human well-being. Source: Adapted from de Groot et al., 2010b.

Table 5.1: Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) classification of ecosystem services

CLASSIFICATION	ECOSYSTEM SERVICE	DESCRIPTION
Regulating contributions	Habitat creation and maintenance	Maintaining the ecosystem structures and processes that allow the other of nature's contributions to people to be provided.
	Pollination and dispersal of seeds and other propagules	The ways that nature contributes to the productivity of plants through fertilizing and dispersing seeds and other vegetative propagules (IPBES, 2016).
	Regulation of air quality	Regulation of CO_2/O_2 balance, ozone for ultraviolet-B absorption and polluting gases.
	Regulation of climate	Including regulating albedo, some aspects of greenhouse gas emissions and carbon sequestration (see Box 5.2).
	Regulation of ocean acidification	Maintaining the pH of the ocean through buffering the increases and decreases of carbonic acid, caused mainly by the uptake of CO_2 in the oceans.

CLASSIFICATION	ECOSYSTEM SERVICE	DESCRIPTION
Regulating contributions (continued)	Regulation of freshwater quantity, location and timing	For direct uses by people and indirect use by biodiversity and natural habitats (*see* Water Resources chapter).
	Regulation of freshwater and coastal water quality	Capacity of healthy terrestrial and aquatic ecosystems to regulate the delivery of water supply and/or filter and retain nutrients, sediments and pathogens affecting water quality (*see* Water Resources chapter).
	Formation, protection and decontamination of soils and sediments	Sediment retention and erosion control, soil formation and maintenance of soil structure, decomposition and nutrient cycling.
	Regulation of natural hazards and extreme events	The role of preserved ecosystems in moderating the impact of floods, storms, landslides, droughts, heat waves and fire.
	Regulation of organisms detrimental to humans	Including pests, pathogens, predators and competitors.
Material contributions	Energy	Biomass-based fuels.
	Food and feed	Wild and domesticated sources, feed for livestock and cultured fish (*see* Sector Impacts and Adaptation chapter).
	Materials and assistance	Production of materials derived from organisms in crops or wild ecosystems for construction, clothing, printing, ornamental purposes or decoration.
	Medicinal, biochemical and genetic resources	Plants, animals and microorganisms that can be used to maintain or protect human health either directly or through organism processes or their parts.

CLASSIFICATION	ECOSYSTEM SERVICE	DESCRIPTION
Non-material contributions	Learning and inspiration	Opportunities from nature for the development of the capabilities that allow humans to prosper through education, acquisition of knowledge and development of skills.
	Physical and psychological experiences	Opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment (*see* Rural and Remote Communities chapter and Sector Impacts and Adaptation chapter).
	Supporting identities	Basis for religious, spiritual and social cohesion experiences, for narrative and story-telling, and for sense of place, purpose, belonging, rootedness or connectedness (*see* Rural and Remote Communities chapter).
	Maintenance of options	Continued existence of a wide variety of species, populations and genotypes to allow yet unknown discoveries and unanticipated uses of natures, and ongoing evolution.

Source: IPBES, 2018.

Box 5.2: Storage of carbon by ecosystems

Many ecosystems sequester and store carbon, helping to reduce the accumulation of greenhouse gases in the atmosphere. Within Canada, the soils of the tundra, forests, wetlands and grasslands are of particular importance for carbon storage. Once ecosystems are disturbed, however, stored carbon—which may have built up for decades, centuries or millennia—is released to the atmosphere (IPBES, 2018). The northern permafrost region contains 1672 Petagram (Pg) of organic carbon, mostly stored in permafrost (i.e., soil or rock that remains frozen from one year to the next), which accounts for approximately 50% of the global belowground carbon pool (Tarnocai et al., 2009). Thawing permafrost due to climate change, however, increases microbial decomposition of organic carbon, releasing it into the atmosphere and triggering a positive feedback process (Schuur et al., 2008). Forest growth can sequester carbon for up to 800 years (Luyssaert et al., 2008); while boreal forests, for instance, store an immense amount of carbon, climate change is threatening their carbon storage capacity (Balshi et al., 2009; Kurz et al., 1999). Wetlands and peatlands also deliver critical services related to carbon capture, and store approximately 450 Pg of carbon (Mitsch and Gosselink, 2015; Lal, 2008). Grasslands store large amounts of carbon in plant biomass and soil, but the degree of storage is dependent on how grasslands are managed, particularly for livestock (Wang et al., 2014).

5.1.4 Direct and indirect drivers of change in ecosystem services

Ecosystems and their services are affected by a range of direct and indirect drivers. The most prominent direct drivers for the degradation of ecosystem services include habitat conversion, fragmentation and overexploitation/overharvesting, with climate change exacerbating the impacts of other drivers and poised to become the leading driver soon (IPBES, 2018). Climate change threatens the viability and resilience of some natural ecosystems and the human societies that depend upon them (Malhi et al., 2020). However, understanding of the complex ways in which ecosystems and the services they provide are affected by climate change is currently incomplete (IPCC, 2019a).

Climate change affects biodiversity and ecosystem services in a multitude of ways. Since biodiversity is critical to ecosystem resilience and functioning, it is important to consider ecosystem services within the context of broader life support systems when investigating climate change impacts, ecosystem responses, climate change adaptation and green house gas (GHG) emissions reduction (Biodiversity Adaptation Working Group, 2018). Appendix 1 provides a more comprehensive review of how climate change threatens different types of ecosystem services, the social and economic consequences of these climate change impacts, and the ways that we can harness ecosystems to adapt to new environmental conditions and reduce GHG emissions. Figure 5.5 illustrates how climate change could impact the extent to which different types of physical, social and economic drivers result in changes to various ecosystem services globally by 2050.

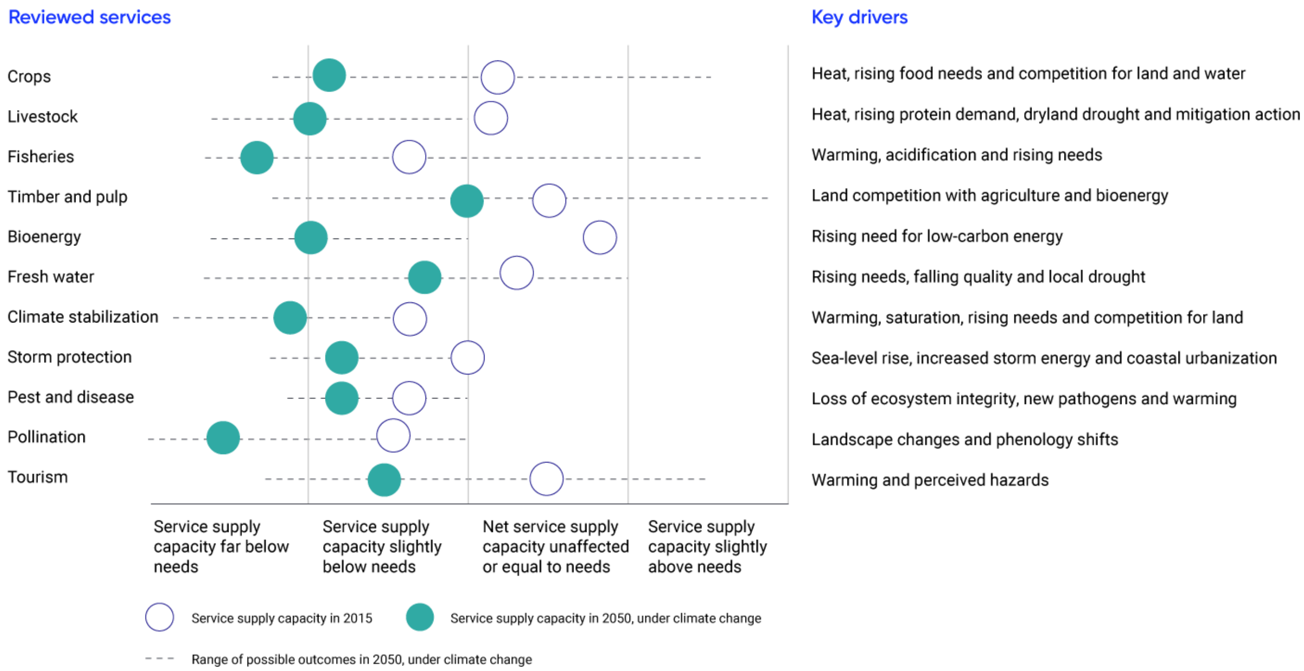


Figure 5.5: A visual summary of the relationship between supply and demand for the ecosystem services surveyed by Scholes (2016), both at the present time (open circles) and around 2050 (filled circles), under climate change. The range of possible outcomes around the year 2050 is depicted with a horizontal bar. Source: Adapted from Scholes, 2016.

Other drivers of ecosystem change include human activities such as land-use change, overexploitation of resources, pollution and changes in water balance. At the global level, infrastructure, farms, settlements and road networks occupy more than 75% of the habitable surface of the Earth (Ellis et al., 2010). Human activities have also affected oceans through, for example, eutrophication and fish stock depletion (Halpern et al., 2008), leaving only about 13% of the ocean that has not experienced human impacts (Jones et al., 2018).

Indirect drivers of ecosystem change include population and demographic trends, patterns of economic growth, weaknesses in governance systems and inequality (IPBES, 2018). Failure to account for the full economic value of ecosystem services in decision making has been identified as a key contributing factor to their loss and degradation (Organisation for Economic Co-operation and Development, 2019).

5.1.5 Feedbacks, thresholds and tipping points

It is critical to recognize that drivers of change, including climate change, do not act on ecosystem services in a linear manner. Ecosystems respond to climate change through: 1) feedbacks that can limit, reduce or further magnify impacts on ecosystems and people; 2) thresholds, where a relatively small change or disturbance (e.g., change in temperature) in external conditions causes a rapid change in an ecosystem; and

3) tipping points that identify the particular threshold where an ecosystem shifts to a new state, significantly changing biodiversity and ecosystem services.

With respect to climate change, a feedback loop is something that accelerates or decelerates a warming trend—these are two-way interactions between climate and ecosystems that amplify or dampen the climate's initial response to elevated GHG concentrations or other external climatic forcings (Kueppers et al., 2007). If the impacts of climate change result in accelerated warming, then this is called a “positive feedback”; if it results in decelerated warming, on the other hand, then this is called a “negative feedback” (*see* Figure 5.6). An example of a positive feedback loop related to climate change is the northward advance of forest vegetation with climate warming, which reduces land surface albedo and thereby promotes additional warming (*see* Figure 5.7).

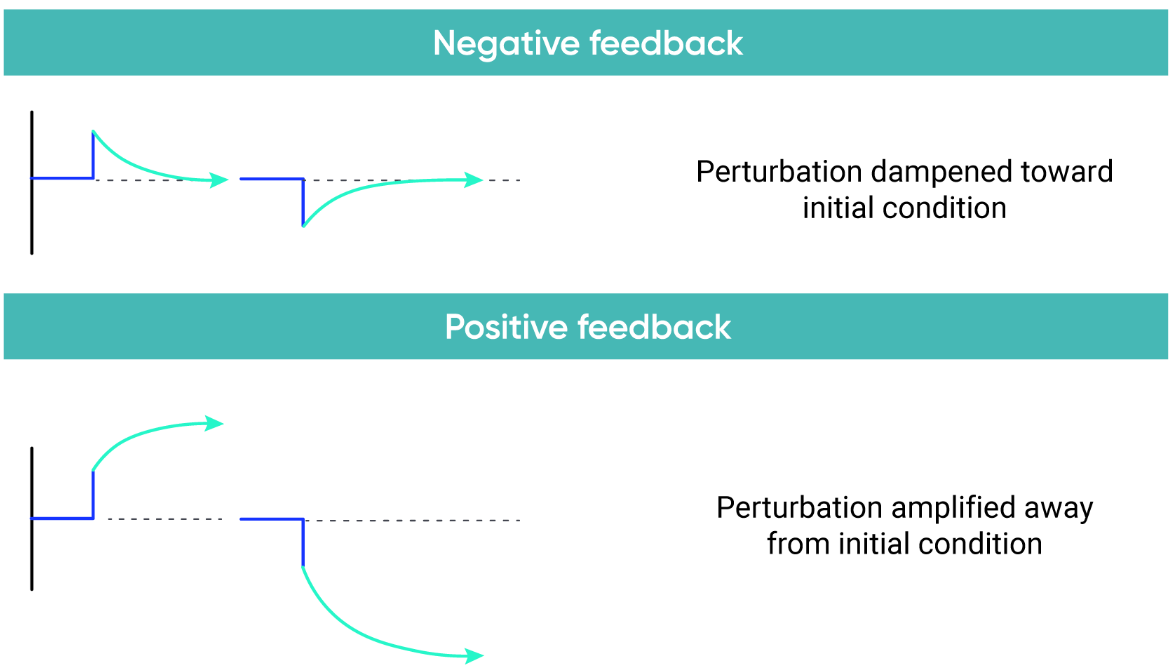


Figure 5.6: Illustration of positive vs. negative feedback loops related to climate-ecosystem interactions. Source: Adapted from Kueppers et al., 2007.

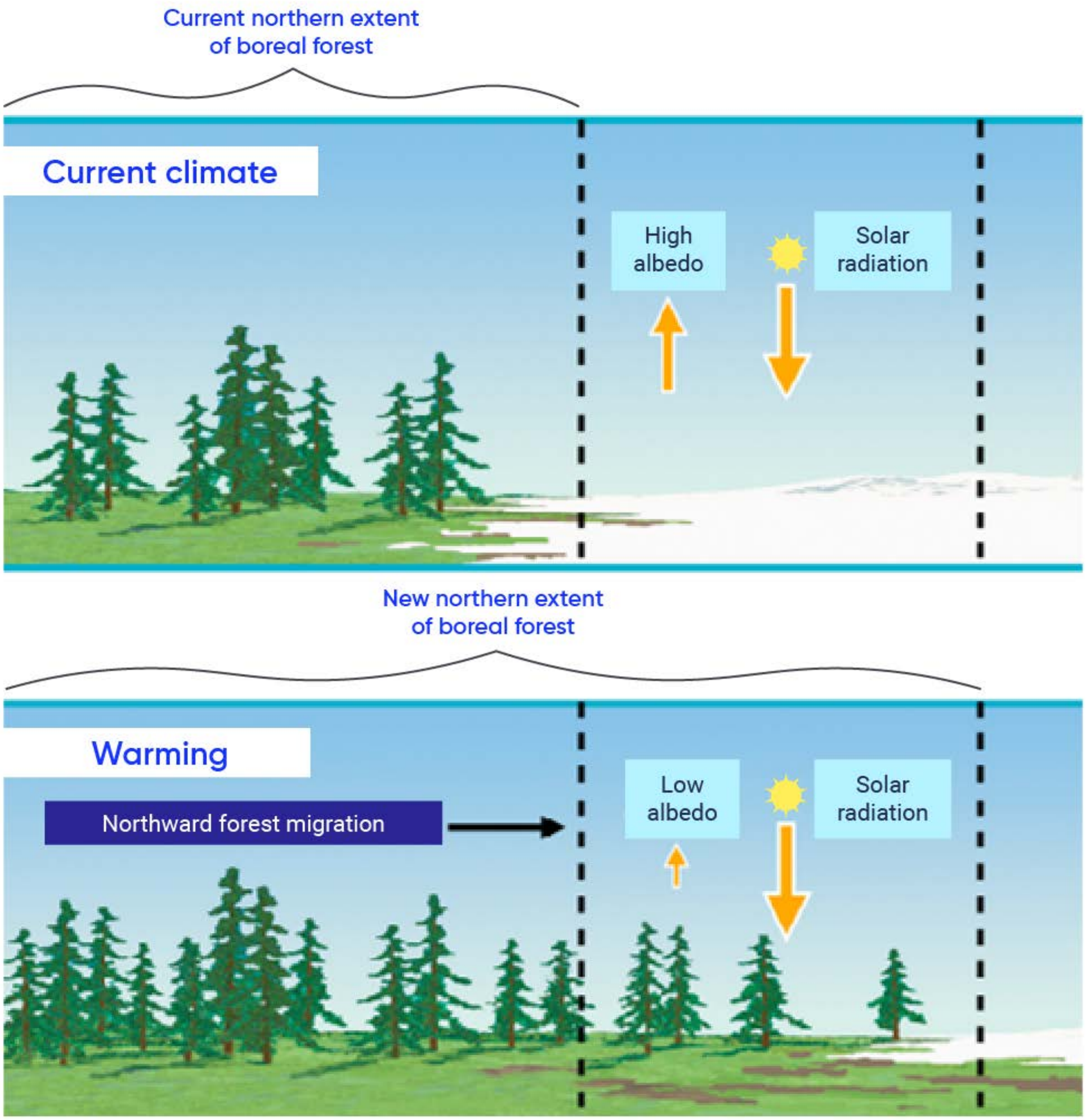


Figure 5.7: Example of a positive feedback loop, whereby the northward advance of forest vegetation due to climate warming reduces land surface albedo, thereby promoting additional warming (a positive climate-ecosystem feedback). Source: Adapted from Kueppers et al., 2007.

Ecosystems are only able to absorb pressure to a particular threshold or tipping point. Beyond these points, large and abrupt changes in ecosystem structure and function occur. Regime shifts caused by the crossing of thresholds tend to be persistent, costly to reverse (if reversal is possible) and can profoundly impact ecosystem services, as well as social and economic well-being (Leadley et al., 2014; Folke et al., 2004;

Scheffer et al., 2001). Improving our understanding of how climate change affects ecosystems and their services, combined with conservation and efforts to maintain ecosystems services (*see* Section 5.2.4), can help to minimize the negative impacts associated with changing conditions.

5.2 Climate change is threatening Canada's ecosystems and the services they provide

Climate change is already affecting the capacity of Canada's ecosystems to provide services. Extreme weather events, in particular, and shifts in seasonal climate patterns are interacting with other pressures on ecosystems causing a range of impacts. These will continue to intensify.

Climate change is already reducing the capacity of ecosystems to deliver services in the long term, including food, water, air purification and climate regulation. Impacts from extreme weather events and changes in climate patterns are of particular concern, both now and as they continue to intensify in the future. Maintaining, restoring and managing ecosystems are key strategies for reducing climate change impacts on the services that they provide.

5.2.1 Introduction

Canada's climate is changing and will continue to change. Ecosystems are sensitive to the changes outlined in Canada's Changing Climate Report (Bush and Lemmen, 2019), including higher temperatures, shifting precipitation patterns, increased risk of floods, drought and wildfire, and loss of sea ice and glaciers. These changes affect species distribution and ecosystems in several ways. First, changes in climate alter the growth of individual species and the timing of critical life events for plant and animal species—a phenomenon known as phenology (Körner and Basler, 2010; Yang and Rudolf, 2009). Second, species generally shift their spatial distributions northward in response to climate change (Chen et al., 2011), but can also shift in multiple directions (VanDerWal et al., 2013), thereby altering biodiversity, and ecosystem composition and functioning (Van der Putten et al., 2010). Third, increased frequency of extreme weather and disturbance events (e.g., heat waves, droughts, storms, fires, pest and disease outbreaks) related to climate change (Dale et al., 2001) can alter species composition and ecosystem functioning (Weed et al., 2013). Disturbances to specific ecosystems and their services are discussed in more detail in Section 5.3.

These climate-related impacts are already affecting the ability of ecosystems to supply services, both negatively and positively, and in many cases are projected to increase in severity as the climate continues to change into the future (Kareiva et al., 2012). Climate change impacts also combine with non-climate stressors (e.g., pollution, overharvesting and habitat loss) to reduce the capacity for species and ecosystems to provide services for human well-being (Nelson et al, 2013; Staudt et al., 2013; Hansen and Hoffman, 2011a).

5.2.2 Phenology

Species rely on a range of natural cues to signal changes in their life cycles—the study of which is referred to as phenology—and some of these cues can be impacted by a changing climate. For example, warmer temperatures can send a signal to migrating birds to arrive at breeding grounds earlier than usual, which is problematic if what they eat is dependent upon seasonal changes and not available until well after their arrival (Møller et al., 2008). At the global scale, there is strong evidence that climate change impacts on phenology are already affecting the timing of migration and breeding, and leading to asynchronies between interacting species (Cohen et al., 2018). Nantel et al. (2014) provide a summary of observed climate change impacts on phenology in Canada. These include earlier flowering of plants in the parklands of Alberta by up to two weeks (Beaubien and Hamann, 2011), delayed emergence from hibernation of Columbian ground squirrels in the Rockies (Lane et al., 2019) and extended autumn flight periods of boreal butterflies by up to one month in Manitoba (Pohl et al., 2014). While species may be able to apply adaptive response strategies to deal with phenological mismatches, these are not always ideal alternatives. For example, puffins in the Maritimes have started eating butterfish instead of herring, which has led to reports of increased juvenile starvation due to the larger butterfish being more difficult to consume (Kress et al., 2016).

The impacts of phenological changes on the provision of ecosystem services have not been widely documented across Canada, but have the potential to be widespread and significant. Consider the predicted increase in the interaction between eastern spruce budworm and black spruce lifecycles, which can lead to loss of biodiversity and potentially reduce the supply of ecosystem services (Donnelly et al., 2011). Another example is how species, such as polar bears and seals, are negatively affected by the loss of sea ice for hunting and mating (Stirling and Derocher, 2012). Also, caribou populations could decline with the loss of important lichen forage habitat or extreme weather events (Joly et al., 2012; Festa-Bianchet et al., 2011). These examples have the potential to negatively impact food webs, including threatening food security for northern communities (*see* Case Story 5.3; Stern and Gaden, 2015) and nature-based recreation in the North (Hall and Saarinen, 2010), even as warmer conditions and sea ice loss lengthen the tourist season (Stewart et al., 2012). There is also evidence of climate change disrupting plant-pollinator interactions, with studies showing complex and uneven responses of pollinators to climate warming (Morton and Rafferty, 2017). Bumblebees, for example appear less able to shift their ranges northward in response to warming, leading to shrinking distributions (Kerr et al., 2015), with implications for the many crops they pollinate.

5.2.3 Changing distributions

Ecosystems and species are shifting in response to changing climate conditions. Place-based observations, meta-analyses and models indicate that climate shifts have already begun to alter the geographical range of plant and animal species on land and in marine systems (IPCC, 2019a, b; 2014), which has implications for ecosystem composition and ecosystem service delivery. Mobile species are likely to shift over longer distances (e.g., birds, pollinators, etc.). Changes in tree species distributions and the poleward migration of freshwater fish appear to be affecting where and how timber harvesting and freshwater fishing occurs in Canada (Poesch et al., 2016; Ste-Marie, 2014).

Range shifts for a variety of tree species in Canada have been observed, including northward shifts in red maple, sugar maple and paper birch (Boisvert-Marsh et al., 2014). There is limited evidence of southward shifts for balsam fir, white spruce and black spruce based on sapling establishment; however, this may be related to the effects of natural or human-induced disturbances (Boisvert-Marsh et al., 2014). In the north, northward shifts in the sub-Arctic tree line have been observed (Rees et al., 2020; Gamache and Payette, 2005), and shrubification is causing an irreversible shift from tundra to shrubland (Fraser et al., 2014, Hill and Henry, 2011; Myers-Smith et al., 2011). These range shifts have implications for a variety of forest-associated ecosystem services, including timber production, carbon storage (*see* Box 5.2), nature-based recreation, the provision of wild food and water quality regulation. Range shifts of forest insects (Nantel et al., 2014) and agricultural pests (*see* Sector Impacts and Adaptation chapter; Campbell et al., 2014) are also likely to impact these services, but in often unpredictable ways (Scheffers et al., 2016), as the exact nature of these changes over space and time is uncertain.

Similarly, range shifts in lake-dwelling fish species have been observed, such as the northward shift in sunfish species of 13 km per decade to occupy more northern lakes in eastern Canada (Alofs et al., 2014). Changing ocean conditions due to climate change have led to substantial geographic shifts in marine animals, a pattern that is expected to continue or accelerate in the future. With rising ocean temperatures, marine species are already shifting poleward (Palacios-Abrantes et al., 2020; Poloczanska et al., 2016) or into deeper water (Dulvy et al., 2008) to stay within their preferred temperature range. Movements can be temporary; for example, greater proportions of Pacific hake (whiting) migrated northward into Canadian waters during the warm 1998 and 2015 El Niño events (Berger et al., 2017). Shifts are also associated with ecological responses and altered food-web interactions, which increase uncertainty of stock productivity and the vulnerability of fish to pollution and exploitation (Cheung, 2018; Cheung et al., 2016). These distribution shifts may simultaneously lead to the loss of native fish (e.g., Arctic cod) and opportunities for new fisheries (Stern and Gaden, 2015). Similar patterns with variable effects across economically-valuable species are expected for other locations in Canada, including the Pacific Coast (Okey et al., 2014) and the Great Lakes (Collingsworth et al., 2017).

Other potential changes to ecosystem services due to shifts in species and ecosystem distributions include the loss of berry production in the Arctic due to shrubification (Stern and Gaden, 2015), tree range expansion (Pearson et al., 2013), increased risk of diseases (such as Lyme disease) as host species (e.g., deer tick) expand their ranges northwards (Ogden et al., 2014; Leighton et al., 2012) and reduced diversity of crop pollinators (Kerr et al., 2015).

The capacity of ecosystems and individual species to adapt to climate change through range shifts, however, is not without limits. Organisms are limited in the range of environments to which they can adapt. Many have limited dispersal ability and there is not always access to newly suitable habitat in which to colonize (Lipton et al., 2018). In coastal regions, for example, beaches, dunes, sand spits, barrier islands and their associated coastal marshes can adjust to increasing sea levels by continuous landward migration (Savard et al., 2016). In some cases, however, this migration is impeded by infrastructure (such as sea walls) or by naturally-rising land (Pontee, 2013). This leads to coastal squeeze, and can result in the loss of coastal marshes and other valuable ecosystems (*see* Case Story 5.1).

Case Story 5.1: Addressing sea-level rise in Boundary Bay, B.C. through a "Living Dyke" approach

Boundary Bay, located in the greater Vancouver area on the west coast of British Columbia, is an important marine ecosystem that provides many ecosystem services to the surrounding communities of Surrey, Delta, White Rock and Semiahmoo First Nation. With 400 ha of salt marsh, the area provides habitat for many species, including juvenile salmon, and is recognized as an Important Bird Area of the Pacific Flyway (IBA Canada, n.d.). The Boundary Bay marsh also provides flood regulation, by reducing the level of wave energy that reaches the approximately 15 km of coastal dykes installed to protect the surrounding communities and regional infrastructure (Carlson, 2020). However, it is projected that by 2100, the salt marsh may be completely inundated and lost due to coastal squeeze (Carlson, 2020)—the intertidal habitat loss that arises due to the high water mark being fixed by the dyke and the low water mark migrating landwards in response to sea-level rise (Pontee, 2013). To prevent this from happening, the City of Surrey, the City of Delta and the Semiahmoo First Nation are collaborating to find an innovative solution.

The "Living Dyke" concept, led by West Coast Environmental Law, seeks to elevate areas of the salt marsh habitat by gradually delivering salt marsh material, coupled with the recurring planting of salt marsh vegetation (SNC-Lavalin Inc., 2018). By raising the marsh slowly over the course of 25 to 30 years, organisms will be able to adapt as they migrate southward, while the marsh continues to provide ecosystem services such as wave protection (SNC-Lavalin Inc., 2018). A roundtable of representatives from federal, provincial and local governments, as well as First Nations, will continuously monitor and evaluate the progress of this pilot project (Carlson, 2020).

5.2.4 Protected and conserved areas

Protected and conserved areas constitute a key component of Canada's approach to climate change adaptation and GHG emissions reduction, and are important tools for maintaining ecosystems and their services (Mitchell et al., 2021). By providing habitat and refuge for biodiversity and sequestering carbon (*see* Box 5.2), protected and conserved areas increase adaptive capacity and the resilience of ecosystems as a whole, while also conserving their ability to deliver ecosystem services. Understanding where ecosystem services are produced and where people benefit from them is another factor to consider when it comes to effectively conserving ecosystems services (Mitchell et al., 2021).

As a party to the Convention on Biological Diversity, Canada has committed to protecting at least 17% of terrestrial areas and inland water, and 10% of coastal and marine areas by 2020 (Biodivcanada, 2020). At the end of 2019, 12.1% of Canada's terrestrial area (land and freshwater) was conserved (including 11.4% in protected areas), and 13.8% of Canada's marine territory, was conserved (including 8.9% in protected areas), having surpassed the original target for marine areas (Government of Canada, 2020).

There are many types of protected and conserved areas, allowing for different activities and resource uses at the national, provincial, territorial and local level. Examples include:

- Indigenous Protected and Conserved Areas (IPCAs) (*see* Case Story 5.4), which are a classification developed through the 2020 Biodiversity Goals and Targets for Canada (Biodivcanada, 2020), in response to Canada's commitment under the Convention on Biological Diversity. This classification recognizes the important leadership role played by Indigenous people in managing their land, as well as the importance that such areas can play in biodiversity conservation and the protection of cultural heritage.
- Large forested national and provincial protected areas, which can serve as an important carbon sink at the global level, while also providing a range of ecosystem services (e.g., improved water and air quality, recreational opportunities for people, refugia for migrating species and pollinators, etc.).
- Protected and conserved areas at the local level—including urban greenspaces, municipal parks and wetlands—which deliver a range of services, such as benefits to human health by reducing the impacts of extreme heat related to climate change (*see* Case Story 5.7 and Section 5.5.2.4).

The national network of protected and conserved areas takes into account diversity across ecosystems and species, and at the genetic level. For instance, more biodiverse forests can sequester more carbon and are better equipped to resist invasions and disease (Bunker et al., 2005). Habitat connectivity is another important consideration for protected and conserved areas in the face of climate change, as species ranges respond and adapt to changing conditions. For instance, the Yellowstone to Yukon initiative is an international effort to link conserved land, and maintain and connect substantial suitable habitat for wildlife to migrate and adapt as needed in a changing climate (Yellowstone to Yukon Conservation Initiative, n.d.). As viable habitats move northwards, it may be necessary to reconsider park and refuge boundaries to continue to protect species, while providing habitat and services for nature and people (Graumlich and Francis, 2010).

5.3 Impacts will vary across Canada's ecosystems and regions

Ecosystem responses to climate change across Canada's regions will vary. Northern, mountainous and coastal regions are especially vulnerable to climate change impacts on ecosystem services, due in large part to limited adaptation options. Strengthening the adaptive capacity of people and communities living in these regions is vital to maintaining ecosystem services.

Climate change is affecting Canada's ecosystems in different ways, affecting their ability to deliver services to the communities that rely on them. Ecosystem responses will also vary depending on their exposure and sensitivity to climate change impacts, and their particular thresholds and tipping points. Understanding, assessing and mapping ecosystem changes, threats to ecosystem services and the vulnerability of communities to these changes can help to identify priority areas and pathways for adaptation. Strengthening the adaptive capacity of the communities that rely on ecosystem services is important for their preservation in the face of a changing climate, and also for minimizing the consequences to these communities in terms of human health, well-being and livelihoods.

5.3.1 Introduction

Climate change impacts on Canada ecosystems will be unevenly distributed across the country (*see* Figure 5.8). Similarly, responses of ecosystems to these changes will also vary (Breshears et al., 2011). In particular, Canada's northern, mountain and coastal regions are projected to *see* large and rapid changes due to climate change (Bush and Lemmen, 2019; IPCC, 2019a; IPBES, 2018). In many of these locations, impacts from climate change are overwhelming the capacity of ecosystems to buffer variability, with accompanying changes to ecosystem services. Managing these changes will challenge the ability of social-ecological systems to react adaptively.

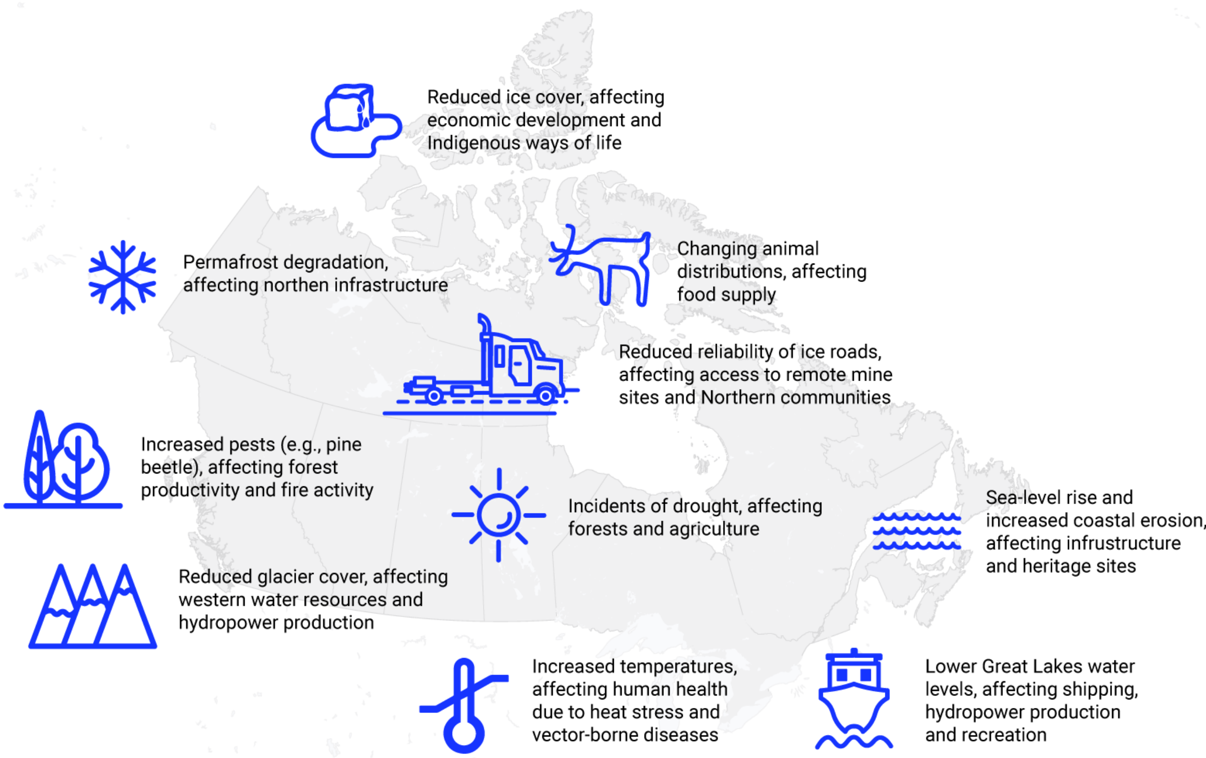


Figure 5.8: Climate change impacts in different regions across Canada, many of which have implications for ecosystems and their services. Source: Adapted from Government of Canada, 2014.

At the same time, certain segments of the Canadian population are more vulnerable to changes in ecosystem services due to their physical location, reliance on these services or socioeconomic status (Pearce et al., 2012; Ford and Pearce, 2010). Examples include Indigenous communities; communities that depend on natural resources for livelihoods (see Rural and Remote Communities chapter); communities located in Arctic, alpine or coastal areas; and individuals that are socioeconomically disadvantaged. While often resilient and adaptive, many of these communities have limited resources, access to technology and alternatives to ecosystem services that they can use to efficiently adapt to changes in ecosystem service provision. Various tools exist that can help to enhance the adaptive capacity of these communities, including by facilitating the integration of biophysical and socioeconomic data into risk identification processes and to support management decisions (see Box 5.3).

Box 5.3: Tools for measuring ecosystem flows

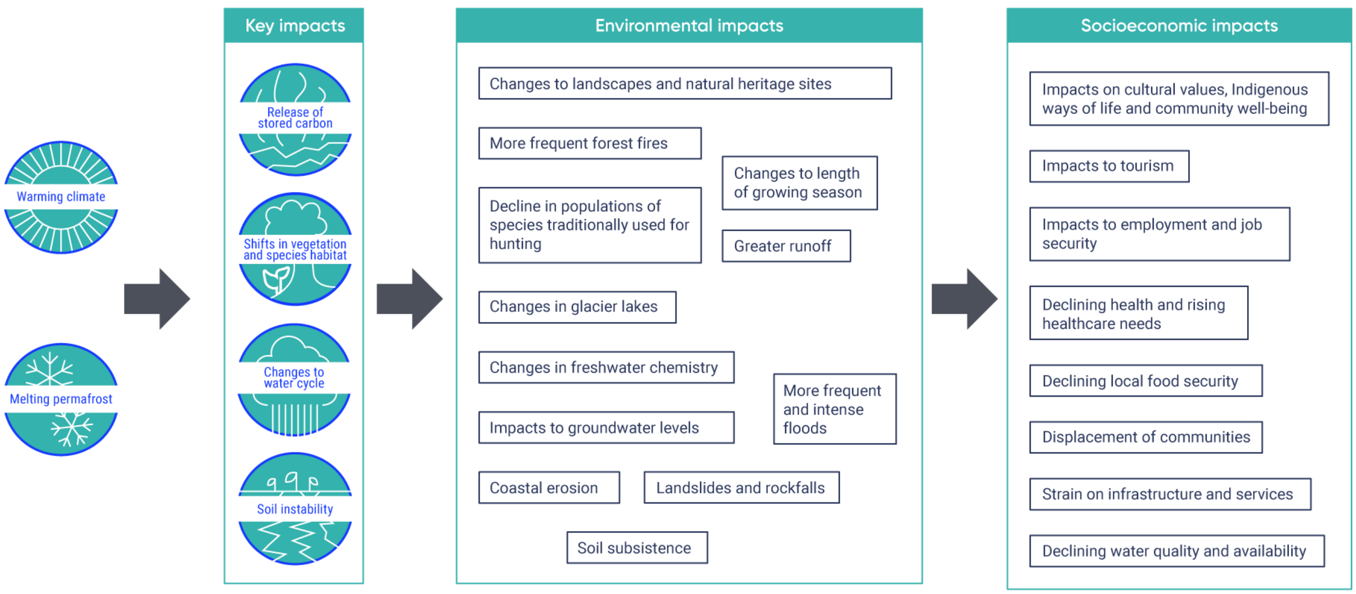
Measuring ecosystem service flows can be challenging due to the many interactions and feedback loops within ecosystems, as well as the influence of political boundaries, jurisdictional regulations and economic factors on management decisions and ultimately ecological outcomes. A variety of strategies have emerged to address measurement challenges, including using ecological boundaries (such as watersheds), proxy indicators, modelling and seeking expert input, as well as using tools to combine different types of ecosystem data. More comprehensive assessment tools and approaches are being sought, including a range of different expertise and types of knowledge (Wei et al., 2017). Threat assessment frameworks are among the various tools that can help to identify how multiple stresses are intensifying climate change impacts and to locate hotspots where ecosystem service supply is decreasing and demand is increasing (Mace et al., 2012). Likewise, ecosystem service maps that include supply and demand, as well as watersheds, economic data and other important values, are useful decision-support tools (Haines-Young et al., 2012; Naidoo et al., 2008).

5.3.2 Northern regions

Northern Canada has warmed and will continue to warm at more than double the global rate (Bush and Lemmen, 2019), with implications for biodiversity and ecosystem functioning (Pithan and Mauritsen, 2014; Screen and Simmonds, 2010). Canada's North is projected to experience increased temperature and precipitation, and decreased snowfall (Cohen et al., 2019; Vavrus et al., 2012; Callaghan et al., 2011), with associated changes in permafrost, sea ice and glaciers (Derksen et al., 2018). Rapid, widespread and significant ecosystem changes that have been observed and/or are expected, include:

- Increased growth of shrubs (shrubification), vegetation shifts and loss of Arctic tundra (Pearson et al., 2013; Myers-Smith et al., 2011);
- Poleward shifts in species and ecosystem distributions, including animal and plant species, and forest ecosystems (Kortsch et al., 2015; Brommer et al., 2012);
- Changes in snow cover, snowmelt, water availability and quality (Evengard et al., 2011);
- Invasions of new fish species and changes to freshwater and marine fisheries (Wassmann et al., 2011);
- Decline in caribou (*see* Case Story 5.3; Cressman, 2020; Mallory and Boyce, 2017), related to reduced access to food due to earlier and faster snowmelt and increasing freeze-thaw cycles, and increased harassment by insects (Cressman, 2020; Johnson et al., 2012; Hansen et al., 2011b).
- Loss of sea ice and negative impacts on polar bear and seal populations (Stirling and Derocher, 2012);
- Thawing of permafrost, destabilizing infrastructure and loss of soil carbon (Schuur et al., 2015); and
- Increases in net primary productivity in some areas in the western Northwest Territories and Yukon (Boone et al., 2018; Stralberg et al., 2018), with implications for carbon dynamics and carbon storage.

These ecological changes will have cascading impacts that affect a wide range of ecosystem services, including food provision, freshwater supply and quality, climate regulation, community health and recreation opportunities (Stern and Gaden, 2015; Allard et al., 2012; Kelly and Gobas, 2001). Cascading impacts are when a hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, and where the resulting impact is significantly larger than the initial impact (IPCC, 2019b). Such impacts are complex and multi-dimensional. For example, projected thawing of permafrost in the Arctic is anticipated to affect plant and animal distributions, which could lead to a decline in hunting species and negative impacts on local food security (*see* Figure 5.9).



Note: This figure provides examples of the cascading environmental and socioeconomic impacts associated with a warming climate and melting permafrost, and is not intended to be comprehensive.

Figure 5.9: The effects of climate change on permafrost and their cascading impacts throughout society and environment. Data source: IPCC, 2019b.

Northern communities are especially vulnerable to ecosystem shifts and the corresponding changes to ecosystem services. Many northern and Indigenous communities rely on provisioning services for their food security—including wild game, marine mammals, fish and plant species (Hoover et al., 2016)—which climate change is already threatening (*see* Case Story 5.3 and [Rural and Remote Communities]() chapter; Beaumier and Ford, 2010; Wesche and Chan, 2010). Alternatives to these food sources are limited and also extremely expensive given transport costs to the North (Mead et al., 2010). As a result, climate change may increase food insecurity in the North. Nature-based recreation, sport hunting and wildlife viewing are important components of northern economies (Chanteloup, 2013); the loss of wildlife species and shifts in their distributions may make these activities more difficult and unpredictable, while also threatening traditional cultural activities (Ford and Pearce, 2010).

Due to their remoteness, small populations and being located near the northern range limits of many species, northern communities tend to have fewer options available for adapting to changes in climate—such as extreme weather events, sea ice decline and thawing of permafrost (with resultant impacts on infrastructure)—thereby affecting their adaptive capacity (Meredith et al., 2019). While Indigenous communities are highly adaptive, limited financial resources and organizational capacity can further constrict adaptation options (*see* Northern Canada chapter; Meredith et al., 2019).

5.3.3 Mountain regions

Canada's mountainous regions are vulnerable to changes in climate, including increased temperatures and rainfall, more extreme weather events, more variable snowfall (Kohler et al., 2014; Gonzalez et al., 2010) and increased frequency of wildfires (Rocca et al., 2014). Alpine species and ecosystems are considered to be especially vulnerable to climate change, as their ability to move to higher altitudes and track climate conditions is limited by the physical height of the mountains where they are located (Rudmann-Maurer et al., 2014). Climate change is projected to result in changes to snowpack (Würzer et al., 2016), loss of mountain glaciers (Shugar and Clague, 2018), the upward movement of the tree line, and the loss of alpine species and ecosystems (Rudmann-Maurer et al., 2014). For example, glaciers of the Columbia Icefield in the Canadian Rocky Mountains experienced dramatic changes from 1919 to 2009, losing 22.5% of their total area while retreating more than 1.1 km on average over this time period (Derksen et al., 2019; Tennant and Menounos, 2013).

These changes are expected to impact key ecosystem services in these regions. In particular, loss of glacier and snow cover in mountain areas and thawing of permafrost, in combination with more extreme rainfall events, is predicted to result in increased rock fall and mudslides in some alpine areas (Huggel et al., 2011). Changes to mountain forests may also compromise their ability to protect against flooding, debris flow, landslide, rock fall and avalanches (Lindner et al., 2010). In addition, increased frequency of disturbances such as fires, wind throws and pest infestations would affect water runoff and quality (Lindner et al., 2010). Finally, landscape aesthetics may be impacted by glacier retreat and the loss of snow-covered areas for significant portions of the year, as well as shifting patterns of recreation as new areas for tourism emerge and people seek out mountain areas as refuge from heat waves (Palomo, 2017). For example, the Canadian Rockies are predicted to see a tourism increase of up to 36% by 2050 driven by warmer weather, but a potential decrease by 2080 as environmental impacts and glacier disappearance reduce the area's suitability for nature-based recreation (Palomo, 2017).

5.3.4 Forested regions

Climate change impacts on forest ecosystems and services will vary across Canada's forested regions and will often be cumulative (*see* Sector Impacts and Adaptation chapter). Climate change is a critical driver of progressive disturbances—such as pest infestations, which influence the likelihood of immediate disturbance events—while also affecting long-term forest structure and composition (van Lierop et al., 2015; Sturrock et al., 2011; Burton, 2010). Increasing disturbance is likely also affecting carbon storage (*see* Box 5.2; Arora et al., 2016; Kurz et al., 2008), recreation and water quality regulation (Ford, 2009).

Increased wind throw risks in eastern Canadian forests, as a consequence of decreased soil frost duration (Saad et al., 2017), and the die-off of aspen from drought in Alberta and Saskatchewan are also anticipated (Michaelian et al., 2010). A similar regional vegetation die-off occurred in the southwestern US due to drought and a bark beetle outbreak in 2002–2003 (Breshears et al., 2005). In this case, tree die-off led to decreased firewood and piñon pine harvesting, reduced soil erosion regulation, altered viewsheds and reduced recreation quality, although it did increase fodder production for cattle (Breshears et al., 2011). Similar changes to forest ecosystem service provision in Canada as a result of climate change may occur in specific regions.

There is an increased risk of wildland fire and drought, in the short term (Boucher et al., 2018; Boulanger et al., 2017a), as increases in temperature are projected to surpass the moderating effects of increasing precipitation on fire weather (Zhang et al., 2019). Across Canada, fire dynamics and resulting impacts on forest ecosystem services will vary substantially (Boulanger et al., 2017a; Hope et al., 2016). This spatial variation in fire activity will have significant impacts on forest ecosystem services and costs of fire suppression across Canadian provinces. For example, the Fort McMurray wildfire of 2016 cost over $3.9 billion (Insurance Bureau of Canada, 2019) and has resulted in long-term and widespread effects on rivers in the region, with resultant impacts on water quality (*see* Water Resources chapter; Emmerton et al., 2020). The potential for "mega-fires" in temperate and boreal forests due to climate change and forest management (e.g., fire suppression) will also increase with climate change (Adams, 2013). These types of large fires can shift vegetation from conifer-dominated boreal forest ecosystems to deciduous ones, or could have the potential to change temperate forests in certain locations to non-forested vegetation (Boulanger et al., 2017b). Such thresholds, if crossed, would have significant impacts on ecosystem services such as carbon storage, timber supply, climate regulation, water provision (since vegetation regrowth reduces available water) and recreation (*see* Sector Impacts and Adaptation chapter; Mina et al., 2017; Adams, 2013).

Various approaches are being used to reduce the impacts of climate change on forest ecosystems and species, such as reducing the risk of fire through active fuel management (e.g., thinning, debris removal and prescribed burning) (Astrup et al., 2018; Schroeder, 2010), planting a greater proportion of fire-tolerant species and deciduous trees (Bernier et al., 2016) and, in certain cases, pursuing assisted migration of vulnerable and important species (*see* Case Story 5.2)

Case Story 5.2: Assisted migration of Whitebark Pine in B.C. and Alberta in response to climate change

As suitable habitat for certain tree species shifts northward under a changing climate, natural migration of tree populations may not occur at the speed required for populations to remain coupled with the ecosystems in which they have evolved (Sáenz-Romero et al. 2021). This decoupling results in abiotic and biotic stresses, such as drought stress, that lead to mass tree mortality (Sáenz-Romero et al., 2021). As climate change progresses, traditional conservation methods may no longer be sufficient for protecting populations and new adaptive strategies may be required (Hällfors et al., 2017)

Assisted migration—"the human assisted relocation of genotypes through reforestation and restoration intended to mitigate future impacts of climate change on forest health and productivity" (Sáenz-Romero et al., 2021, p. 2)—is an emerging adaptation strategy that is gaining attention globally. By expanding populations in the direction that climate change will eventually take them, forest health and the ecosystem services they provide can be maintained.

Whitebark Pine (*Pinus albicaulis*) is a tree species that is foundational to diverse high elevation and sub-alpine ecosystems in the mountainous areas of British Columbia and Alberta. Its root systems help to stabilize snow, moisture and soil, and its large nutritious seeds feed a variety of bird and mammal species including Clark's nutcrackers, red squirrels and bears (Government of British Columbia, 2021). The Whitebark Pine has been listed as "endangered" under Canada's Species at Risk Act since 2012, due to its population being in steep decline over much of its range (*see* Figure 5.10). This is resulting from the combined effects of drivers such as the Mountain Pine Beetle, an introduced pathogen that causes white pine blister rust (*Cronartium ribicola*), and climate change (Government of Canada, 2011). It is projected that Whitebark Pine will be largely extirpated from its current range over the next 70 years (McLane and Aitken, 2012).

The recovery strategy for the Whitebark Pine in Canada (ECCC, 2017) reports that assisted migration techniques may need to be part of the approach used to combat habitat loss as a result of climate change, and that suitable habitat for growth needs to be identified. Field tests have been initiated to assess the capacity for assisted migration of Whitebark Pine within predicted future ranges (Sáenz-Romero et al., 2021; McLane and Aitken, 2012). One study found that the successful establishment of Whitebark Pine outside of its current range is possible, but there are certain factors that must be considered (Sáenz-Romero et al., 2021), including the potential for natural seed dispersal (i.e., whether the bird species responsible for most of the dispersal in the current species range will follow the assisted range shift) and the degree of public support for assisted migration outside of the current range (e.g., there may be resistance by local and/or Indigenous communities in introducing a non-native species into the proposed areas).

Despite the ongoing debate on the long-term success or appropriate methods of assisted migration, there is a general agreement that more field studies are needed to better evaluate and quantify the effectiveness of this approach as a long-term climate change adaptation strategy (Bucharova, 2017).

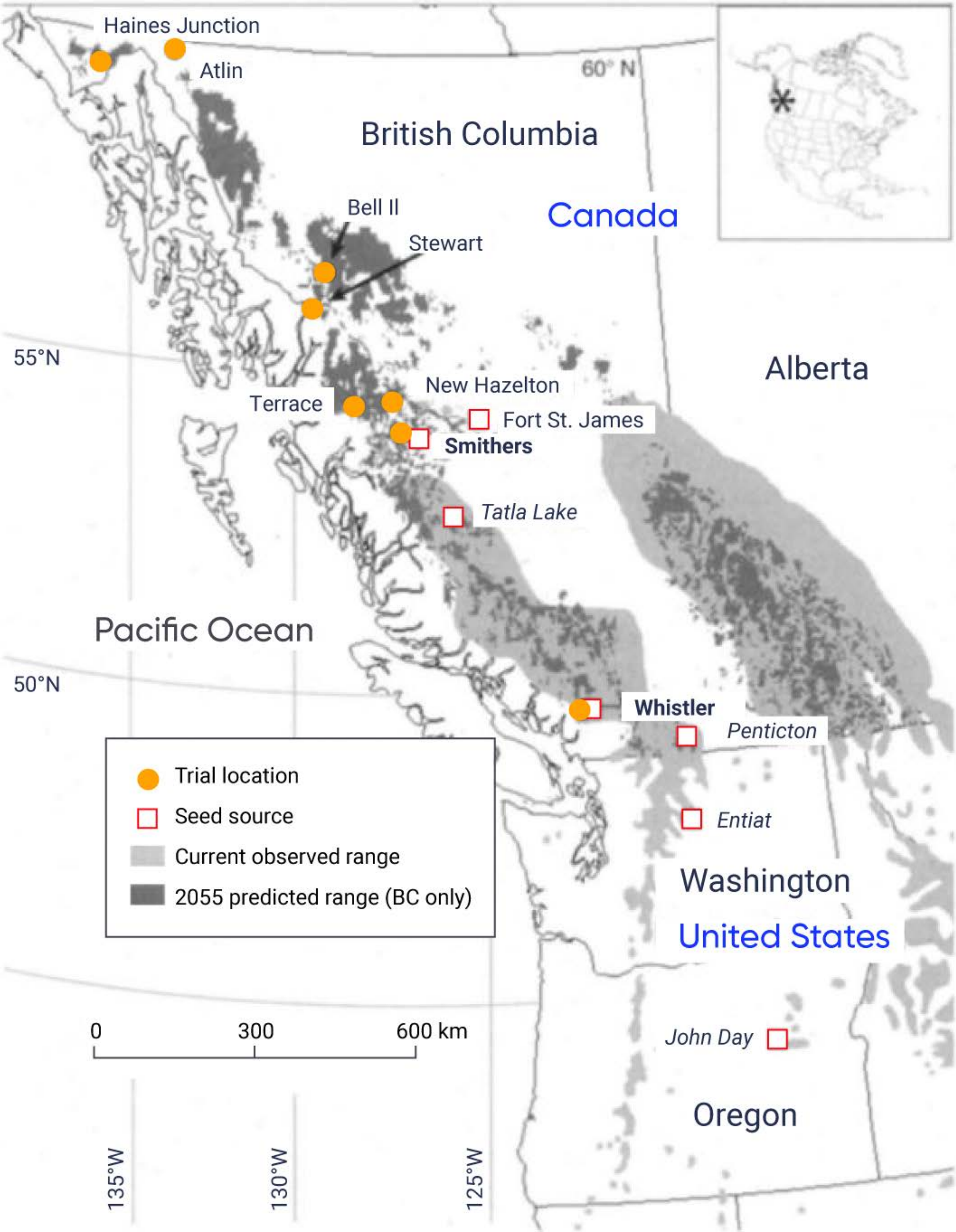


Figure 5.10: Map of the current observed range and predicted future range in 2055 for Whitebark Pine (*Pinus albicaulis*), as well as trial locations for the assisted migration experiment. Source: Adapted from Sáenz-Romero et al., 2021.

5.3.5 Coastal regions

Canada has the world's longest coastline, measuring over 240,000 kilometers (Taylor et al., 2014). Coastal regions are home to approximately 6.5 million Canadians and are a defining element of our national identity (Lemmen et al., 2016), as well as critical contributors to the economy (Association of Canadian Port Authorities, 2021, 2013). Given the importance of coastal ecosystems for coastal protection, erosion control, marine fisheries, carbon storage, habitat-fishery linkages and recreation (Barbier et al., 2011), the loss and degradation of coastal areas are likely to have substantial impacts on the provision of ecosystem services from these regions (Bernhardt and Leslie, 2013). The extent of impacts to ecosystems and people will depend on the success of adaptation measures.

Although the impacts of climate change on marine ecosystems remain poorly quantified (Lemmen et al., 2016), documented climate risks within Canada include higher temperatures and changing precipitation patterns, more intense storm surge events, changing sea levels, diminishing sea ice, changes to hydrology (including glacier melt) and changes to ocean-water properties (e.g., temperature, salinity, acidification and hypoxia) (Lemmen et al., 2016). The impacts of changes in sea ice, sea level changes and ocean acidity are briefly reviewed in the Sector Impacts and Adaptation chapter.

Rising sea level can lead to the reduction and loss of important coastal habitats such as salt marshes through a process known as "coastal squeeze" (Savard et al., 2016; Hartig et al., 2002). This occurs when ecosystems are unable to migrate landward in response to sea level rise due to a barrier, such as a sea wall or cliff (*see* Case Story 5.1; Atkinson et al., 2016). Projections of changes in sea level up to 2100 fluctuate from a rise of almost 100 cm in some East and West Coast regions, to an equivalent fall in sea level (i.e., of almost 100 cm) in some central North Coast regions (Lemmen et al., 2016), due to differences in vertical land motion (e.g., Atkinson et al., 2016). Rising sea levels will lead to increased risk of flooding, inundation and, in some instances, will threaten the viability of low-lying communities, particularly when coastal storms intensify the effects of sea-level rise (Yang et al., 2014).

The North and East Coast regions are experiencing changes to the extent, thickness and duration of sea ice, with declines in extent ranging from about 2.9–10% per decade in the North and 2.7% per decade since 1969 in areas of the East Coast (Canadian Ice Service, 2007). Impacts to people are most pronounced in the North, where changes to sea ice have made travel more dangerous, affected subsistence species (*see* Figure 5.11), compromised traditional harvesting activities and impacted well-being (Lemmen et al., 2016). Lastly, increasing ocean acidity threatens shellfish and other aquatic organisms, which can impact food provision from fisheries and aquaculture operations in the East and West Coast regions.

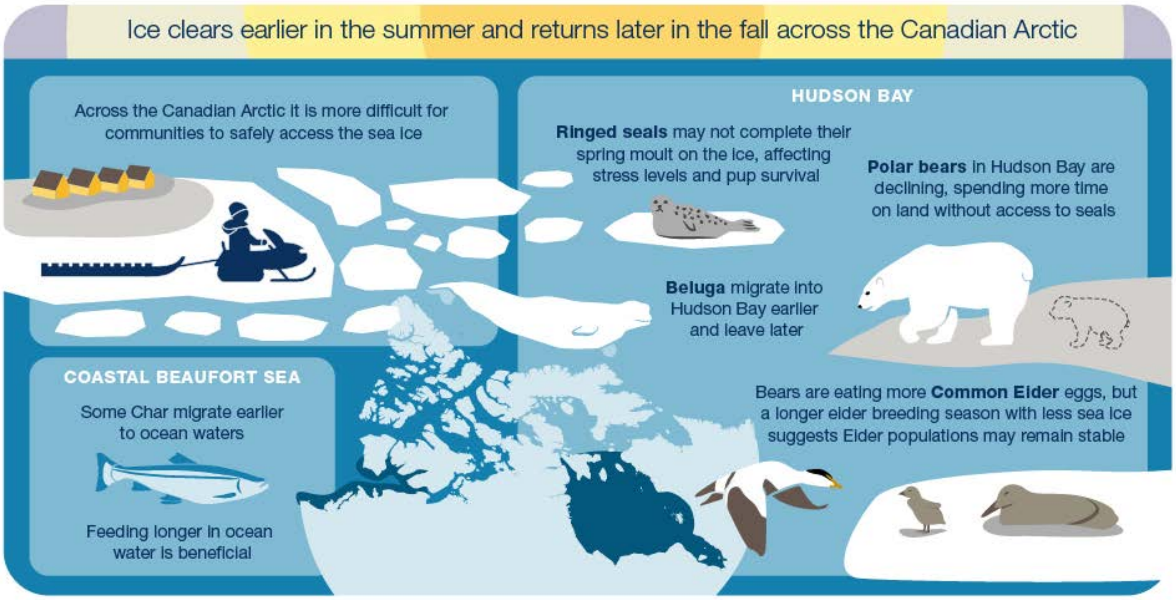


Figure 5.11: Impacts of changes in sea ice on species used for food or other purposes (subsistence species). Source: Department of Fisheries and Oceans Canada, 2019.

5.3.6 Enhancing adaptive capacity

Strengthening the capacity of vulnerable communities to adapt to climate change (i.e., adaptive capacity) is key to facilitating successful adaptation to changes in ecosystem services resulting from climate change. Adaptive capacity can take a variety of forms. Indigenous Knowledge has provided and will continue to provide an important foundation for climate change adaptation (Pearce et al., 2015) in the face of changes to ecosystem services (*see* Section 5.4 and Case Story 5.3). Diversified sources of livelihood and economic support, and regional planning initiatives that work to collectively conserve and manage ecosystem services also increase adaptive capacity (*see* Rural and Remote Communities chapter).

Increased educational, logistical and financial resources to support the management and restoration of key ecosystems that provide ecosystem services enhance adaptive capacity (Keesstra et al., 2018). Maintaining and restoring coastal ecosystems, for instance, can reduce the vulnerability of coastal areas to climate change impacts and to the associated loss or reduction in ecosystem services (*see* Case Story 5.1 and Case Story 5.6). These measures are most effective when specific climate change and ecosystem service risks and hazards are identified and incorporated into nature-based approaches to adaptation (*see* Section 5.5; Wamsler et al., 2016).

It is also important to address barriers to adaptive capacity. Comprehensive assessments of vulnerability to changes in ecosystem services and capacity to adapt to future climate change impacts have not been completed for Canada (e.g., Ford and Pearce, 2010). These could, however, help to identify opportunities for enhancing adaptive capacity with respect to ecosystem services (Boyd, 2010). In particular, most studies focus on the biophysical impacts of climate change and ecosystem services, but few studies consider the equally important socioeconomic aspects (Ford and Pearce, 2010) or seek to understand how to incorporate this information into management decisions (Keenan, 2015). This lack of information and knowledge will make it difficult for vulnerable communities, which often have limited resources and information, to adapt to the ecosystem service impacts of climate change.

5.4 Indigenous Knowledge is vital to maintaining ecosystems

Indigenous Knowledge is critical for maintaining ecosystems and the services they provide in a changing climate. Indigenous Knowledge Systems encompass different perspectives for understanding environmental complexity, and provide strategies to reduce, manage and adapt to environmental change in a place-based and holistic manner.

Indigenous peoples are increasingly taking a leadership role in addressing the challenges of climate change and environmental degradation. Given their close connections to nature and the land, Indigenous peoples are closely attuned to, and often directly affected by, changes in ecosystems and their services, which can have important ties to their culture and identity. Future land-use management practices can be better informed by Indigenous Knowledge in a way that optimizes ecological, cultural and economic benefits across their traditional territories and beyond.

5.4.1 Introduction

Indigenous peoples in Canada—including First Nations, Inuit and Métis—have been leading the protection and conservation of their traditional territories and homelands for millennia. Today, this continues through the work of Indigenous Water Protectors, Guardians, Watchmen and many other Indigenous-led initiatives to champion resiliency and harmony with Mother Earth. Indigenous peoples have strong cultural and spiritual connections to land and water, as well as long histories of adapting to social and environmental changes. They have often resided for millennia in their territories through the learning and sharing of adaptive knowledge (Houde, 2007), and this has led in many cases to increases in local biodiversity (Harlan, 1995; Blackburn and Anderson, 1993). For instance, a recent study found that Indigenous-managed lands in Canada have slightly greater levels of vertebrate biodiversity than protected areas, while also supporting a greater number of threatened vertebrate species (Schuster et al., 2019). Partnerships between Indigenous communities and other government agencies could further enhance biodiversity conservation efforts.

However, the decoupling of Indigenous lifestyles from traditional lands and the degradation of the environment can erode cultural practices, language and local ecological knowledge, ultimately compromising the sustainability of both cultural and environmental systems. Worldwide and within Canada, significant portions of Indigenous populations live in regions—such as coastal, low-lying and flood-prone areas—that are particularly vulnerable to the impacts of climate change. Indigenous populations also tend to practice resource-based livelihoods; depend upon the land as a source of food, traditional medicine and identity; and continue to live with the impacts of colonization and historical trauma. Climate change often exacerbates these pre-existing conditions (Pearce et al., 2015; Berrang-Ford et al., 2012; Nakashima et al., 2012).

5.4.2 Indigenous ways of knowing

It would be misleading to imply that a list of common cultural traits could describe the richness and diversity of Indigenous peoples. Within Canada, there exists a wide variety of nations, customs, traditions, languages and worldviews. Nonetheless, there are similarities between Indigenous Knowledge Systems (ways of knowing). These relate to in-depth knowledge of place accumulated over long timeframes, as well as a framework for understanding complexity.

Indigenous Knowledge has been described as a process that explores how constituent parts of a system interrelate, and how the systems they are a part of change over time and relate to larger systems (Berkes, 1998). It is a cumulative body of knowledge, practice and values, which are acquired through experience and observations on the land or from spiritual teachings, and handed down from generation to generation (Noongwook et al., 2007; Government of Northwest Territories, 2005; Cruikshank, 1998; Huntington, 1998). This may include an understanding of the interrelationships that occur among species, their connections within the biophysical environment, the spatial distributions and historical trends of spatial and population patterns. This form of knowledge evolves over long time periods and involves constant learning-by-doing, experimenting and knowledge-building (Houde, 2007; Neis et al., 1999; Nickels, 1999; Duerden and Kuhn, 1998; Ferguson and Messier, 1997; Mailhot, 1993; Freeman, 1992; Johnson, 1992a, b). Indigenous Knowledge provides insights, for example, to:

- Understand the condition of, and changes to, ecosystem service functions within traditional territories, serving as a means of measuring ecological integrity and resilience;
- Provide early warnings of stressors to the natural environment (e.g., changes among plant or animal species), including to the impacts of climate change (Olsson et al., 2004); and
- Create an expanded and multidimensional picture of adaptation related to concepts such as flexibility (e.g., responding to changes in seasonal cycles of harvest and resource use), hazard avoidance (from detailed knowledge of the local environment and understanding of ecosystem processes) and emergency preparedness (e.g., knowledge of how to respond in emergency situations) (Pearce et al., 2015).

The growing realization that many management policies fail to account for the complexity of ecosystems or local contexts has driven the need for new adaptive processes to cope with change (Houde, 2007; Gunderson, 1999; Holling and Meffe, 1996). Indigenous Knowledge provides insights into implications for livelihoods, cultures and ways of life, as well as locally-appropriate and culturally-relevant adaptation strategies (*see* Case Story 5.3 and Rural and Remote Communities chapter; Pearce et al., 2015; Ford and Pearce, 2012; Pearce et al., 2011) by building quantitative and qualitative data from a large number of variables (Berkes and Berkes, 2008). Recognizing that Indigenous Knowledge Systems differ from non-Indigenous Knowledge and that they form an equal part in policy development, programs and decision making yields richer and more balanced outcomes for maintaining ecosystems and their services, upon which many Indigenous communities rely.

Case Story 5.3: Preserving Tłı̨chǫ culture in the face of declining Barren ground caribou populations

The Tłı̨chǫ people are working to build resilience in the face of climate change impacts on their land and culture. The Tłı̨chǫ people, whose traditional territory lies within the Northwest Territories, have witnessed dramatic climate change impacts on their most culturally and socially important animal, the ekwò or barrenland caribou (also referred to as the Barren ground or Bathurst caribou). The Tłı̨chǫ people depend on the caribou herd not only for food, but also for clothing and equipment (*see* Figure 5.12 and Figure 5.13). This keystone species, located at the centre of Tłı̨chǫ culture, is in rapid decline and climate change is playing a significant role (Cressman, 2020; Mallory and Boyce, 2017). Earlier, quicker snowmelt and increasing freeze-thaw cycles throughout the year have decreased food availability and increased harassment by insects, compounding stresses on the herd and resulting in higher instances of starvation and calf mortality (Cressman, 2020; Johnson et al., 2012; Hansen et al., 2011b).

Surveys of the caribou population show that the barrenland herd has been declining sharply for decades, from 472,000 animals in 1986 to only 8,200 animals in 2018 (Government of Northwest Territories, n.d.). To protect the barrenland caribou, and in turn the Tłı̨chǫ culture, the Tłı̨chǫ Government and the Government of the Northwest Territories placed a ban on barrenland caribou harvest in 2015, which is still in effect. Due to the decline of caribou, the Tłı̨chǫ people do not go to the barrenlands as often, where they share traditional knowledge, learn the language and go hunting with their families (Galloway and Arvidson, 2020). Losing the caribou entirely poses even greater risks to a part of the Tłı̨chǫ identity and culture. It is important for these communities to have agency in adapting to these changes and support in undertaking their approaches to adaptation.

The Tłı̨chǫ Government, with support from Indigenous Services Canada, initiated the Tłı̨chǫ Dǫtaàts'eedı program ("to share food among the people") in 2018 in all four Tłı̨chǫ communities. The program pairs young adults with experienced harvesters to go fishing, hunting, trapping, snaring and berry picking. Food that is harvested is brought to the community and distributed by the youth to Elders. The program not only addresses the impacts of climate change, but also does so in a way that reinforces food security, and Tłı̨chǫ values and culture (Cressman, 2020). Young people who participate in the program spend time on the land learning traditional skills and provide a service to their communities, while interacting with Elders. When the Tłı̨chǫ Dǫtaàts'eedı program concludes in March 2021, more than 100 youth and 60 harvesters will have collectively distributed approximately 4,000 kg of fish and meat to community Elders. The program enables communities to adapt to the impacts of climate change with cultural knowledge transfer, working with the land, using traditional skills and empowering youth (Cressman, 2020).

Figure 5.12: An Elder from Wekweètì teaches a younger member of the community to scrape and tan Caribou hides. Hides are soaked and stretched over a board before being scraped with a k'edze, a tool made from a Caribou's lower leg bone. Photo courtesy of Vanita Zoe.

Figure 5.13: Clothing and tools made by artisans in Wekweètì from tanned Caribou hide. Photo courtesy of Pat Kane.

5.4.3 Co-management and Indigenous-led natural resource management

Co-management arrangements that are designed to involve Indigenous peoples from the initial, strategic stages of planning allow for improved, holistic decision making and Indigenous empowerment over the activities taking place on their land (Houde, 2007). This may require flexible legal frameworks to allow for co-management arrangements that change and adapt over time, as trust builds between partners (Houde, 2007). Indigenous ownership and control of their Indigenous Knowledge must be respected. Recognizing the fundamental rights of Indigenous Knowledge holders includes sharing of the monetary benefits obtained from the use of this knowledge (Mauro and Hardison, 2000).

Knowledge co-production—the contribution of multiple knowledge sources and capacities to co-create knowledge—requires open partners who are willing to proceed with humility (Moller et al., 2009b). It is also important to recognize that there are limits to the extent to which scientific and Indigenous Knowledge Systems can be combined. Given that they are based on different methodologies and world views, care must be taken to ensure that knowledge is not blended or extracted from its cultural context so that it retains its own integrity (Moller et al., 2009a; Parlee et al., 2005; Davidson-Hunt and Berkes, 2003). One knowledge system does not need the other to corroborate it in order for it to be perceived as valid (The Indigenous Circle of Experts, 2018).

Canada's response to the Convention on Biological Diversity (Minister of Supply and Services Canada, 1995) provides guidance on applying Indigenous Knowledge through a code of ethical conduct, which advises to:

- Respect, preserve and maintain the knowledge, innovations and practices of Indigenous and local communities, embodying traditional lifestyles relevant to the conservation of biological diversity and sustainable use of natural resources;
- Promote the wider application of Indigenous Knowledge with the approval and involvement of the holders of such knowledge; and
- Encourage the equitable sharing of the benefits that arise from the utilization of such knowledge.

Indigenous peoples across Canada are playing an important role in demonstrating leadership on climate action, stewardship and the maintenance of ecosystem services. This can be seen through efforts to safeguard carbon sinks and the development of adaptation solutions—including nature-based approaches and the development and management of Indigenous Protected and Conserved Areas (*see* Case Story 5.4)—as well as through the implementation of innovative GHG emissions reduction technologies and approaches.

Case Story 5.4: Maintaining ecosystems and their services through Indigenous Protected and Conserved Areas

Indigenous Protected and Conserved Areas (IPCAs) refer to lands and waters where Indigenous governments have the primary role in conserving and maintaining ecosystems through Indigenous laws, governance and knowledge systems (*see* Figure 5.14; The Indigenous Circle of Experts, 2018). They aim to support ecosystems and biodiversity while safeguarding Indigenous rights, including the right to exercise free, prior and informed consent. Examples include Tribal Parks, Indigenous Cultural Landscapes, Indigenous Protected Areas and Indigenous conserved areas.

The need for restoration of the land and the culture is often an important component of IPCAs. Indigenous peoples are beginning to lead the call for restoration of lands that have been heavily affected by industrial development and degradation from human activities. Driven by the recognition that people, culture and their lands are inseparable, priority restoration areas are being identified for wildlife, as well as degraded cultural values. IPCAs can also provide safe, nurturing places for people to gain strength and heal from a legacy of intergenerational trauma and the ongoing stress of biological and cultural loss, while deepening their relationship to and understanding of the land.

The IPCA model is rooted in the exercise of constitutionally-upheld Indigenous rights in accordance with Indigenous laws. Exercising agency in how these lands are managed, restored and protected resonates with Section 35 of Canada's Constitution, as well as international declarations that Canada has pledged to support—such as the United Nations Declaration on the Rights of Indigenous Peoples—securing a space where communities can actively practice Indigenous ways of life. The model also aligns with the Government of Canada's Federal Adaptation Policy Framework, which promotes the consideration of Indigenous Knowledge in decision making.

IPCAs can also deliver important benefits to Canadians. Increasing the amount of protected and conserved areas in Canada has positive implications for biodiversity and ecosystems, which in turn contributes to maintaining the important ecosystem services that many communities rely on. However, much work remains to enable IPCAs as a viable option for protecting natural areas and to secure these areas from development pressures.

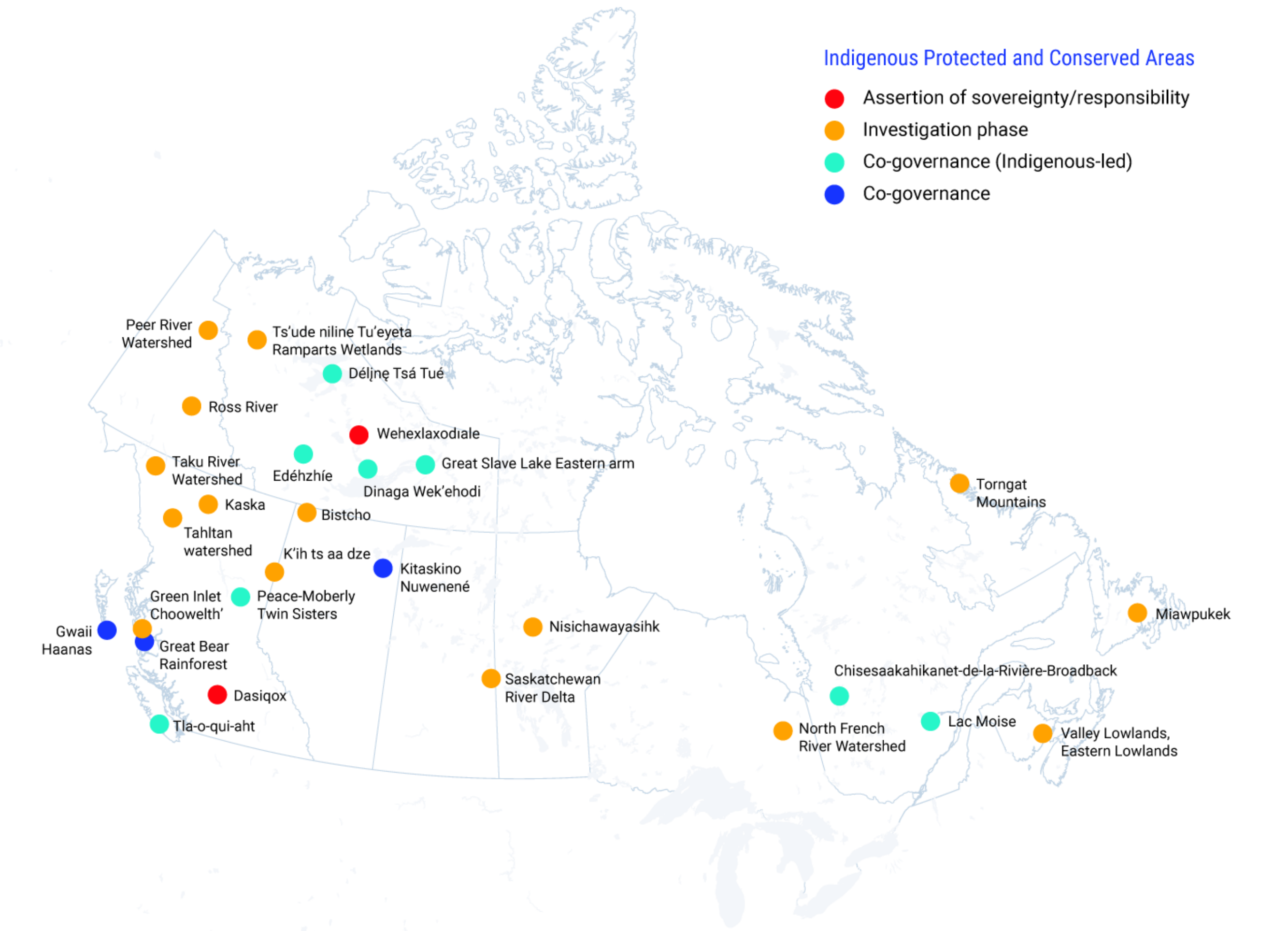


Figure 5.14: Map of Canada outlining locations of existing and proposed Indigenous Protected and Conserved Areas (note: the map is not a complete picture and some areas remain missing and disputed). Source: Adapted from David Suzuki Foundation.

5.5 Nature-based approaches to adaptation maximize benefits

Nature-based approaches to adaptation reduce climate change risks to communities, and are often cost-effective and flexible compared with engineered alternatives. They also deliver a wide range of social, environmental and economic co-benefits, and help to strengthen the adaptive capacity of communities.

There is a rapidly growing interest in nature-based approaches to climate change adaptation in Canada. Nature-based approaches for addressing climate change impacts—such as marshland restoration, low impact shoreline development and urban forests—are wide-ranging and tend to offer significant benefits over engineered adaptation options. They have embedded flexibility that allows for greater degrees of uncertainty in future climatic and environmental conditions, and have been shown to deliver a wide range of social, environmental and economic co-benefits, maximizing overall returns on investment. Furthermore, nature-based approaches contribute to strengthening the adaptive capacity of the communities that they are intended to serve, while reducing risks associated with a changing climate.

5.5.1 Introduction

Ecosystems and nature-based approaches to adaptation can play an important role in reducing climate change risks to communities by providing buffering capacity, strengthening the adaptive capacity of society and social-ecological systems, and contributing to GHG emissions reduction efforts through carbon storage (*see* Box 5.2). However, the potential and limits of nature-based approaches to adaptation are generally not well understood or quantified (Malhi et al., 2020).

5.5.2 Nature-based approaches to adaptation

Within the context of this section, "nature-based approaches" is used as an umbrella term for the range of approaches to adaptation that are nature-driven—including nature-based solutions, natural infrastructure, ecosystem-based approaches, natural asset management and protected areas. These approaches are rooted in the knowledge that healthy ecosystems, whether natural or managed, provide a diverse range of services that benefit human activity, health and well-being. These approaches also allow for flexibility and learning, which is important when addressing uncertainty and complexity in decision making. Nature-based approaches to adaptation are a rapidly growing area of interest in Canada and are also gaining international recognition. Leading economic and environmental organizations—including the IPBES, Intergovernmental Panel on Climate Change (IPCC), Global Adaptation Commission, United Nations and World Economic Forum—are just a few that have endorsed the approach.

Nature-based approaches encompass strategies that integrate the management of land, water and living resources (Convention on Biological Diversity, 2020). Such approaches position decision makers to manage for multiple benefits and build resiliency to change by considering ecosystems as a whole. For example, managing forests for timber production alone would produce different results than also managing for biodiversity and species at risk, while also considering erosion and carbon sequestration. Similarly, a nature-based approach to commercially-valuable seafood considers the range of interactions within and between coastal ecosystems.

Multiple benefits can be gained through the use of nature-based approaches, for both climate change adaptation and GHG emissions reduction, including (*see* Figure 5.15; IISD, 2019; Raymond et. al, 2017):

- Reduced impact of flooding;
- Protection from storm surges and saline intrusion;
- Provision of habitat and biodiversity preservation;
- Carbon sequestration;
- Protection against erosion;
- Drought mitigation;
- Regulation of water flow and supply;
- Improvement of place attractiveness;
- Improvements to health, well-being and quality of life; and
- Creation of green jobs.

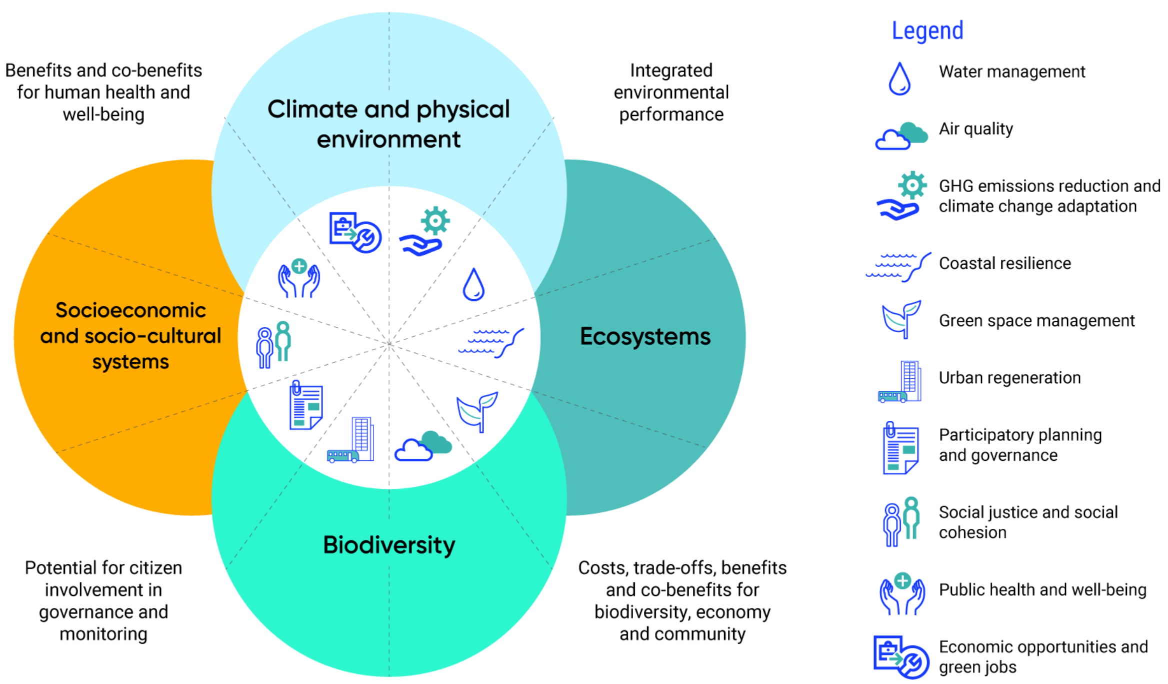


Figure 5.15: Framework used by Raymond et al. (2017) for the assessment of co-benefits from nature-based approaches. Source: Adapted from Raymond et al., 2017.

The role of nature-based approaches is evolving rapidly, as interest and the knowledge base grows. This section discusses different types of nature-based approaches and includes a series of case stories describing these approaches in practice. Future assessments will have a more robust body of existing knowledge to draw from and will discuss the topic in greater detail.

5.5.2.1 Marshland restoration in response to sea-level rise

Restoration of riparian zones and riverine buffers support water infiltration, reduce erosion and regulate water availability throughout a season. Municipalities are increasingly acquiring and restoring land in floodplains (*see* Case Story 5.5), as well as restricting development in flood-prone regions through insurance regulation (e.g., in Montreal). For example, the Tantramar Marshlands near Sackville, NB, are an ecologically and culturally significant region that is at risk from sea-level rise and increased inland flooding events (Wilson et al., 2012). Traditional infrastructure in the form of dykes are being installed to alleviate flooding, alongside salt marsh restoration—a nature-based approach to adaptation. Restored salt marsh can provide flexible protection from certain climate change impacts (*see* Case Story 5.1 and Case Story 5.5; van Proosdij et al, 2016). In addition to addressing water level concerns, salt marshes provide habitat for birds and marine species, trap sediment and distribute nutrients to key coastal species (Deegan et al., 2012). Recognizing the important role of wetlands in combating climate change and its impacts, an allocation of $1.8 million from the $75 million federal Coast Restoration Fund was announced in 2018 for further wetland and marsh restoration of 75 hectares in the Bay of Fundy, NB.

Case Story 5.5: Restoring tidal wetlands and their ecosystem services in Truro, Nova Scotia

Tidal wetlands form the first line of defense during severe storm events; however, the development of Nova Scotia's coastlines has led to the loss of nearly 85% of tidal wetlands (Hanson and Calkins, 1996). In the Upper Bay of Fundy—the area with the highest tides in the world—projected sea-level rise, under a high emissions scenario, is close to 1.2 m by 2100 (Greenberg et al., 2012). A large portion of the wetland habitat loss can be attributed to hardened coastal protection measures (such as dykes, berms and shore armouring), which are already beginning to fail with current storm surges and sea-level rise (Sherren et al., 2019).

Truro, Nova Scotia is a town of 12,000 people, located on the floodplain of the Salmon River that flows into the Bay of Fundy, and is part of a large network of dykes along the Salmon River. These dykes were originally constructed to protect agricultural lands from flooding. Due to increased development over the years, however, they are now also protecting residential, commercial and transportation infrastructure (Sherren et al., 2019). The confluence of the Salmon River and North River creates complex patterns of water, sediment and ice movement in the area, making this site very challenging to manage and resulting in high maintenance costs for dyke and aboiteau infrastructure (Sherren et al., 2019). Although Truro regularly experiences frequent and severe flooding from the combined effects of rainwater accumulation, high tides and ice jams, a particular flooding event in 2012 breached a dyke in several places, which resulted in significant damage to infrastructure. The Province of Nova Scotia performed emergency repairs on the dyke, but there is concern about the long-term maintenance and functionality of the dyke system (Cottar, 2019).

To ensure the long-term protection of the community and to maintain the coastal ecosystem, a Joint Flood Advisory Committee was formed, with representatives from the County of Colchester, Town of Truro, Millbrook First Nation and provincial government departments and the public. The committee commissioned a comprehensive flood risk study of Truro that recommended several options for reducing flood risk (CBCL Ltd., 2017). Of the options provided, no single solution was found to be effective and no measure under CAD$100 million was found to protect more than 20% of the priority areas (Sherren et al., 2019). This led to the stakeholders' decision to opt for managed retreat, allowing for the shortening and realignment of the dyke and restoration of the tidal wetland (*see* Figure 5.16). The restored tidal wetland will foster a range of ecosystem services—fish nursery habitat, storm buffer and carbon sequestration to name a few (ICF, 2018). It is estimated that within three years post-breach, the restored North Onslow tidal wetland will be operating as a near optimum salt marsh habitat and regulating (e.g. acting as a storm buffer) ecosystem services.

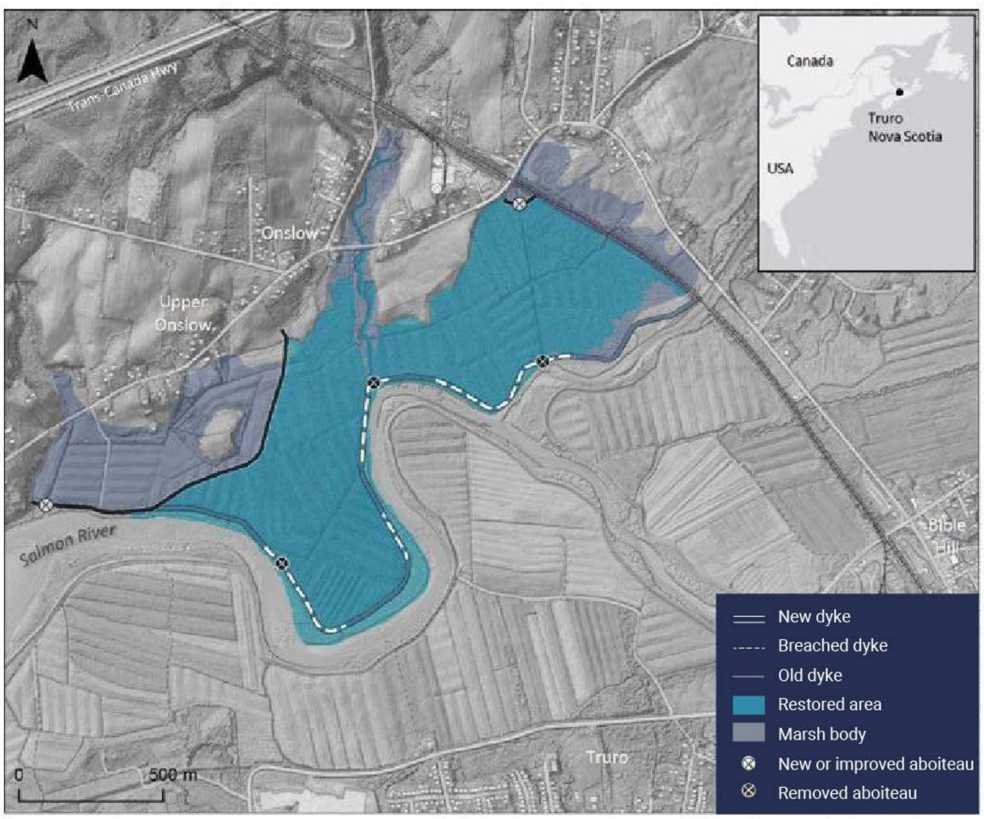


Figure 5.16: Map of the North Onslow marsh in Truro, NS illustrating the extent of the area to be restored as a tidal wetland. Source: Sherren et al., 2019.

5.5.2.2 Low impact shoreline development

Low impact shoreline development is an approach that can be used for waterfront property owners and managers to develop their properties in a shore-friendly way that helps to preserve or restore physical processes, maintain or enhance habitat function and diversity along the shoreline, prevent or reduce pollutants entering the aquatic environment, and avoid or reduce cumulative impacts (Green Shores, 2021). In B.C., the voluntary and incentive-based rating program, Green Shores, is providing training, credit and rating guidance, as well as certification for nature-based shoreline development that reduces impacts on ecosystems and increases resilience to climate change (*see* Case Story 5.6).

Case Story 5.6: Promoting ecosystem-friendly shoreline development through the Green Shores program

A large portion of Canada's coastline is developed, which has implications for the overall health of shoreline ecosystems and the services they provide. With climate change, Canada's coasts and coastal communities are vulnerable to climate change impacts such as sea level rise, storm surge, flooding and increased erosion. There is growing recognition that "hard" or engineered structures alone are not always the most appropriate or cost-effective approaches for reducing these risks. Programs like Green Shores and the Municipal Natural Assets Initiative (MNAI) are contributing to the evidence-base on the effectiveness of nature-based approaches for addressing impacts of climate change on coastal ecosystems, and several programs across Canada are now supporting the implementation of natural shorelines in developed areas (Eyzaguirre et al., 2020).

The Stewardship Centre for British Columbia (SCBC) runs the Green Shores program—a voluntary and incentive based rating program that seeks to reduce the impact of residential development on shoreline ecosystems (SCBC, n.d.). The program offers capacity building, tools and best practice standards to encourage approaches to shoreline development that protect the land from flooding and erosion (with consideration for projected sea-level rise of one metre or more by 2100 for coastal shorelines), increase the ability to access shorelines for recreation, and maintain and restore natural habitats (Eyzaguirre et al., 2020).

In 2018, SCBC and ESSA Technologies Ltd. released the findings from a joint study on the impact and social, environmental and economic value of the Green Shores program. The study also provided recommendations for improving the delivery of the program in BC, and on strategies for making the program available in Atlantic Canada. Recommendations for improving program delivery include (Eyzaguirre et al., 2020):

- Incorporating appropriate incentives for landowners (e.g., payment for ecosystem services or user pay models);
- Strengthening linkages with other change-makers in the system (e.g., identifying areas of overlap and complementary tools with leaders such as MNAI);

- Delivering targeted education and outreach to address barriers and opportunities (e.g., working with contractors to better share information about incorporating soft shoreline protection in development projects); and
- Enhancing learning and monitoring of current and planned Green Shores projects to increase acceptance of soft and hybrid shoreline approaches (e.g., enhancing long-term monitoring of projects).

The report also featured several successful projects that went through the Green Shores program, including the New Brighton Park Shoreline Habitat Restoration Project in Vancouver, BC (Eyzaguirre et al., 2020). This project achieved a Gold rating through the Green Shores program and involved elongating the original shoreline from 150 m to 440 m through the creation of tidal marsh channels (*see* Figure 5.17). The study also undertook an economic analysis of the project, finding that for every $1 spent, social welfare increased by $2.50 (Eyzaguirre et al., 2020).

The findings from this report add to the mounting evidence on the socioeconomic merits of using nature-based approaches to promote more sustainable and resilient shoreline management in Canada.

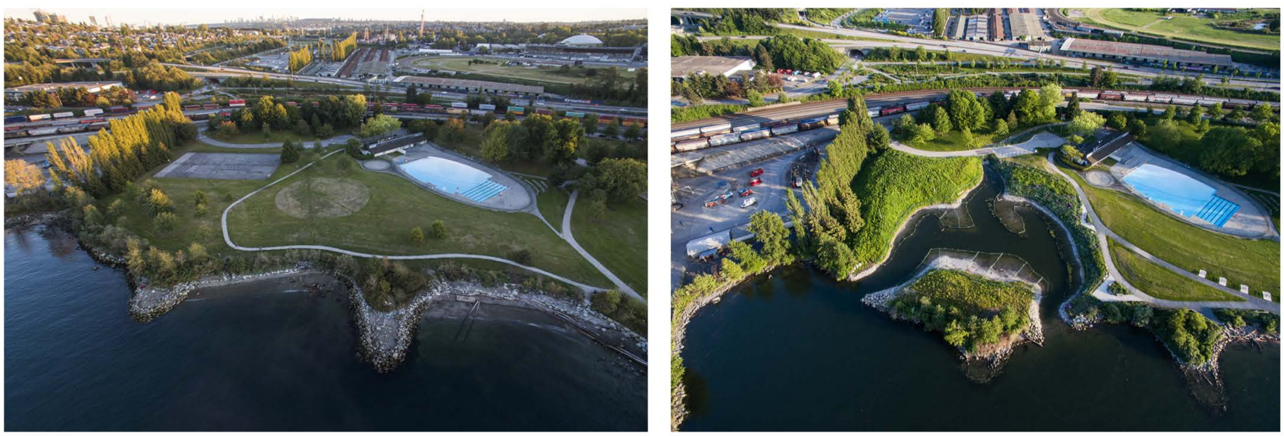


Figure 5.17: Photographs of the New Brighton Park Shoreline Habitat Restoration Project in Vancouver, B.C. prior to the project starting and in 2018, when the project was completed. Photos courtesy of the Vancouver Fraser Port Authority.

5.5.2.3 Urban forests

Urban forests provide ecosystem services evaluated at $330 million per year for Halifax, Montreal, Vancouver and Toronto, without including the value associated with tourism, recreation or increased property values (Alexander and DePratto, 2014). They also deliver a wide range of benefits and can help to reduce impacts associated with climate change impacts (*see* Case Story 5.7), such as higher temperatures and heat waves (Sinnett, 2018; Brandt et al., 2016; Livesley et al., 2016; Rahman et al., 2015), while also storing water and reducing stormwater runoff (Berland et al., 2017; Bartens et al., 2008) and contributing to carbon sequestration (Nowak and Crane, 2001). They also deliver a number of social and economic benefits, including (Bardekjian, 2018):

- Promoting physical activity by providing space for recreation and creating an appealing outdoor environment;
- Promoting mental well-being and stress reduction;
- Promoting social interaction and a sense of community, including stronger ties to neighbours, a greater sense of safety, and more use of outdoor public spaces;
- Making cities more beautiful and hiding unattractive features like walls, freeways, and parking lots;
- Reducing air pollution and provide oxygen; and
- Helping provide habitat for wildlife and preserve biodiversity.

Case Story 5.7: Addressing urban heat island in Kingston, Ontario by increasing the urban tree canopy

Canada's urban centres are projected to see an increase in the annual number of extreme heat days (over 30°C) as a result of climate change (Climate Atlas of Canada, 2019), which have a wide range of health-related implications for Canadians. Many urban surfaces continue to radiate heat captured throughout the day, which can result in as much as a 12°C difference between cities and their surrounding areas at night (Climate Atlas of Canada, 2019). Urban areas also tend to have fewer trees and less vegetation, which provide important cooling services through shading and increased evapotranspiration.

To help address the heat island effect, the City of Kingston, Ontario released their Urban Forest Management Plan (SENES Consultants Ltd., 2011) in 2011. The goal of the plan was to establish guidelines and actions for the City to maintain its urban forest cover at the time (21% coverage in 2009), to support the expansion of the urban forest and to ensure its long term preservation in line with the plan's 25 year vision. The City's official plan outlines a target of achieving 30% urban forest coverage (at a minimum) by 2025 (City of Kingston, 2019). Kingston's urban forest is estimated to generate roughly $1.87 million annually in environmental benefits (SENES Consultants Ltd., 2011). The increase in urban tree canopy will not only help to reduce the heat island effect in Kingston, but can provide:

- shade for buildings in the summer;
- habitat for animals;
- filtration of air pollution;
- filtration and reduction of the amount of stormwater runoff;
- bank stabilization along open watercourses;

- natural wind breaks; and
- an increase in the aesthetic beauty of the city.

The success of the Urban Forest Management Plan is supported by other City of Kingston policies and measures, including its Official Plan, Drought Protection Strategy, Tree Bylaw and a Tree Watering Alert system to engage the citizens (City of Kingston, 2021). The creation of a tree advisory board that included local stakeholders and representatives from the local conservation authority and Parks Canada has also contributed to the plan's implementation (Guilbault, 2016).

5.5.2.4 Greenways and greenbelts around urban areas

Several urban centres in Canada (e.g., the National Capital Region in Ottawa, Ontario; Calgary, Alberta; Saskatoon, Saskatchewan; and the Greater Toronto Area, Ontario) have developed greenways around the cities to conserve green space and maintain the ecosystems in the region and the services they provide (*see* Case Story 5.8).

Case Story 5.8: Ecosystem services provided by Ontario's Greenbelt

In Southern Ontario, where the rapidly growing urban area is home to more than one third of the Canadian population, there is concern associated with development risk to forests, wetlands and agricultural lands, which provide key food provisioning, carbon sequestration, water filtration and key habitat, including for species at risk. The Government of Ontario's Greenbelt Act (2005) led to the production of a land-use plan covering 7,200 km^2, which extends 325 km from the eastern end of the Oak Ridges Moraine in the east to the Niagara River in the west (Ministry of Municipal Affairs, 2017).

Although the Ontario Greenbelt was primarily created to guard against urban sprawl, it is aligned with Ontario's Climate Change Strategy (2015). The Greenbelt, while sensitive to changes in climate, also plays a role in adaptation by helping to protect biodiversity, allowing agriculture and food systems to adapt to climate change and providing a refuge from the heat of urban centres (Friends of the Greenbelt Foundation, 2011). While ecosystem valuations vary in their methodologies, one study has estimated the value of additional ecosystem services provided by the Greenbelt, including recreation, carbon sequestration and flood protection for private property to be over $3.2 billion dollars per year (Green Analytics, 2016).

5.5.2.5 Nature-based vs. engineered approaches

While adaptation is often associated with technological innovations or new infrastructure, strategic maintenance and management of natural systems can yield similar outcomes that are less expensive than engineered options and often deliver additional benefits beyond the targeted issue (Shreve and Kelman, 2014). Recent syntheses found that restored habitats for coastal defence (e.g., salt marshes and mangroves) are cost-effective alternatives to traditional infrastructure, with significantly lower costs for certain habitats (Morris et al., 2018; Narayan et al., 2016).

A 2014 study evaluated the effectiveness of three "soft" or nature-based approaches in BC for addressing sea-level rise, in comparison to equally appropriate "hard" or engineered approaches (Lamont et al, 2014). The "soft" approaches in question included a beach nourishment/shore replenishment alternative, use of nearshore intertidal rock features and use of a typical headland beach system to maintain a conventional beach. The study found that in the three case examples, the "soft" alternatives provided a significant cost advantage over the "hard" alternatives, with a margin of cost savings ranging from 30–70% of the cost of the "hard" alternative (Lamont et al., 2014). Other examples of cost-benefit analysis can be found in the Costs and Benefits of Climate Change Impacts and Adaptation chapter.

The Green Infrastructure Guide for Water Management discusses ecosystem-based management approaches for water-related infrastructure projects (UNEP, 2014). The guide outlines nature-based approaches that are relevant for water resources management—this also includes approaches that consist of built or "grey" elements, which interact with natural features to enhance water-related ecosystem services (see Table 5.2; UNEP, 2014). At the municipal level, the approach of natural asset management has also been gaining traction in recent years (see Case Story 5.9 and Cities and Towns chapter).

Table 5.2: Nature-based approaches for water resource management

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Water supply regulation (including drought mitigation)		Re/afforestation and forest conservation	■				• Dams and groundwater pumping • Water distribution systems
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Water harvesting*	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
Water quality regulation	Water purification	Re-afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Water quality regulation (continued)	Water purification (continued)	Green spaces (bioretention and infiltration)			■		Water treatment plant
		Permeable pavements*			■		
	Erosion control	Re-afforestation and forest conservation	■				Reinforcement of slopes
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
	Biological control	Re-afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Water quality regulation (continued)	Water temperature control	Re-afforestation and forest conservation	■				Dams
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (shading of water ways)			■		
Moderation of extreme events (floods)	Riverine flood control	Re-afforestation and forest conservation	■				Dams and levees
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/ conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Establishing flood bypasses		■			

WATER MANAGEMENT ISSUE (PRIMARY SERVICE TO BE PROVIDED)		GREEN INFRASTRUCTURE SOLUTION	LOCATION				CORRESPONDING GREY INFRASTRUCTURE SOLUTION (AT THE PRIMARY SERVICE LEVEL)
			WATERSHED	FLOODPLAIN	URBAN	COASTAL	
Moderation of extreme events (floods) (continued)	Urban stormwater runoff	Green roofs			■		Urban stormwater infrastructure
		Green spaces (bioretention and infiltration)			■		
		Water harvesting*	■	■	■		
		Permeable pavements*			■		
	Coastal flood (storm) control	Maintaining/restoring mangroves, coastal marshes and dunes				■	Sea walls
		Maintaining/restoring reefs (coral/oyster)				■	

Note: Green infrastructure solutions marked with '*' consist of a hybrid of "green" and "grey" elements that interact to enhance ecosystem services.

Source: UNEP, 2014.

Case Story 5.9: Municipal natural asset management and service delivery

The Municipal Natural Assets Initiative (MNAI) was established in 2016 to refine, test and scale up natural asset management work that was first initiated by the Town of Gibsons, B.C. The initiative is changing the way in which municipalities across Canada deliver services and increase the quality and resilience of natural infrastructure in the face of climate change at lower costs and reduced risk.

The MNAI is testing how to manage natural assets such as woodlands, wetlands and creeks in urban areas as part of a sustainable infrastructure strategy. This approach identifies and determines the value of natural assets, and accounts for their contribution to municipal government services delivery—services that would otherwise need to be delivered by engineered assets. Municipal natural assets are defined by MNAI as the stock of natural resources or ecosystems that a municipality, regional district, or other form of local government could rely upon or manage for the sustainable provision of one or more local government services.

New approaches to manage natural assets are being driven by declining urban infrastructure that is expensive to replace, by the dramatic decline in natural ecosystems, and the urgency of addressing infrastructure challenges in the face of growing populations and climate change impacts such as floods and droughts. Canadian local governments that are seeking new strategies to better deliver core services in a financially sustainable manner are turning to asset management.

Evidence from the MNAI suggests that an asset management-based approach holds great promise for tackling the twin challenges of deteriorating quality of urban infrastructure and declining ecosystem health. For instance, Table 5.3 provides an overview of water-related municipal services that have the potential to be provided by natural assets and ecosystem services, instead of engineered approaches.

The MNAI's lifecycle view of natural assets includes completing an inventory of a community's existing assets, determining the current state and value of those assets, and implementing asset management plans to maintain or replace them. The emphasis on asset management for sustainable service delivery—as opposed to the underlying asset that delivers those services—means that natural capital can form a core element of municipal asset management strategies.

The MNAI team developed a methodology and guidance documents to help local governments identify, valuate and manage natural assets within traditional financial and asset management planning frameworks. Encouraging early results from cohort communities across the country are providing support for this concept. The Gibsons' aquifer, for example, was found to provide sufficient water storage to supply about 70% of the town's projected population for the foreseeable future (Waterline Resources Inc., 2013), with no capital costs and operating costs of $30,000 per year for monitoring—a fraction of the cost of engineered water supply infrastructure.

The first cohort communities—the City of Nanaimo, B.C., City of Grand Forks, B.C., District of West Vancouver, B.C., Region of Peel, ON and the Town of Oakville, ON—assessed the value of stormwater services provided by a natural asset under various scenarios. While results from each project were unique, they shared some key findings: natural assets were found to provide equivalent stormwater management services to engineered ones, and all communities found that their natural asset of interest was meeting at least the 100-year flood storage requirements under current standards. The value of natural assets was also found to increase under scenarios associated with both climate change and intensified development. Overall, early results of the MNAI demonstrate that newly-recognized ecosystem service values are improving local government understanding of how nature is providing municipal services and impacting decision making.

Table 5.3: Examples of water-related municipal services that can be provided by natural assets and ecosystem services

MUNICIPAL WATER SERVICES	ECOSYSTEM SERVICE	NATURAL ASSET	ENGINEERED REPLACEMENT
Drinking water supply	Aquifer recharge	Aquifer and source water area	Pipes for bringing in water supply, water treatment plant
	Lake recharge	Lake watershed	
	River headwaters	Headwater lands	
Drinking water treatment	Water purification	Wetlands, forests, vegetation	Water treatment plant
	Water filtration		
Stormwater Management	Rainwater absorption	Wetlands, forests, vegetation	Stormwater pipes, culverts, storm drains, stormwater ponds
	Rainwater filtration		Water treatment plant
Flood Mitigation	Rainwater absorption	Wetlands, forests, vegetation	Dams, retaining walls, embankments

Source: Adapted from MNAI, 2019.

5.6 Moving forward

There are a number of emerging issues, knowledge gaps and research needs related to how climate change is affecting ecosystem services, and to help integrate ecosystem service considerations and adaptation opportunities into climate change planning.

5.6.1 Knowledge gaps

While there is ongoing research on biodiversity and ecosystem services across the country, there are areas where further knowledge is needed.

5.6.1.1 Climate change impacts to ecosystems and their services

Considering the complexity of ecosystems, it is challenging to anticipate the multitude of ways in which climate change will affect individual species, interactions between species, changes in ecosystem processes and functions, and how these various changes will translate to impacts for ecosystem services.

Additional research is also needed to better understand how changes to ecosystem services under a changing climate will affect the communities that rely on them for livelihoods, health and well-being. Comprehensive assessments of vulnerability to changes in ecosystem services and capacity to adapt to future climate change impacts would help to identify opportunities for enhancing adaptive capacity with respect to ecosystem services (Boyd, 2010).

5.6.1.2 Data and information

More open source data, national standards on what constitutes successful and sustainable nature-based approaches, metrics, approaches for monitoring and inventories, and improved collection and sharing of baseline data would support more cohesive and coordinated biodiversity research on climate change impacts and adaptation (Biodiversity Adaptation Working Group, 2018). Specific data and information needs include:

- Improvements of spatial datasets and indicators of ecosystem service flows;
- More data on the impacts of phenological changes on ecosystem services and non-monetary valuation of ecosystem service flows;
- Development of metrics and standards (beyond forests) to track rates of land-based and coastal carbon sequestration and storage;
- Better identification of hotspots of vulnerability and resilience; and
- Increased monitoring to understand the effectiveness of adaptation approaches.

Gaps also exist in the mechanisms for providing access to information and facilitating collaboration beyond government agencies. Accessible guidance, resources and tools are also needed to support decision makers in integrating adaptation and landscape-level resilience through ecosystem service approaches.

5.6.2 Emerging issues

Achieving and maintaining resilient ecosystems, communities and economies will benefit all Canadians. As research and implementation of climate change strategies emerge and evolve, there are several areas where progress may advance quickly, as well as issues that require further attention. This section highlights some emerging issues that may play key roles in the resilience conversation with respect to ecosystem services, as it moves forward.

5.6.2.1 Valuation of nature-based approaches

Valuing ecosystem services and natural assets, applying different approaches to decision making and assessing the costs and benefits of nature-based approaches to adaptation compared with engineered approaches are rapidly evolving areas of work that are gaining considerable interest and profile in Canada.

With increased incidences of flooding across Canadian urban centres and in coastal regions, there is renewed interest in valuing and utilizing nature-based approaches to meet needs that are normally provided by "grey" or engineered infrastructure. For example, forests and wetlands reduce the impact of floods, soil erosion and landslides, while improving water security (Seddon et al., 2020), as well as providing further ecological benefits (e.g., providing habitat, cultural services, etc.) and cost savings.

Municipalities are making economic arguments for maintaining natural systems to provide needed services, particularly those related to water provision and regulation (*see* Case Story 5.9). Currently, a range of approaches to valuation have been applied, including replacement cost (where services have the potential to align with Public Sector Accounting Board requirements), restoration costs (where Low Impact Development is utilized), and land value (where management requires transfer of ownership rights). In the process, it is important for municipalities to recognize that natural systems can be overwhelmed when their capacity is exceeded, and begin to consider natural systems as a component of a sustainable infrastructure strategy that includes both "grey" and natural components.

5.6.2.2 Improved integration of Indigenous Knowledge

As highlighted in Section 5.4, improved integration and consideration of Indigenous Knowledge will play an important role in addressing climate change impacts to ecosystems and their services, and for adaptation planning across Canada. This cannot be done without acknowledging the harms that have historically eroded trust between Indigenous groups and settler communities. As part of the national effort to commit deeply to the truth and reconciliation process, capacity building and empowering Indigenous leadership and autonomy are important elements in partnering and deeply engaging with Indigenous communities on climate change.

5.6.2.3 Growing role for citizen science

With mobile technology and applications that permit real-time data-sharing about natural phenomena to online repositories (e.g., for water quality, migrating birds, documenting flowering times, etc.), citizens can participate in improving the coverage of knowledge related to changes in ecosystem services, while also becoming involved in tracking changes across the country. Many tools are available to leverage human interest in monitoring information with a great deal of coverage, for very little cost. Interest in participating in unique activities has created opportunities to gather monitoring information in a number of places that could not feasibly be monitored previously, and this interest can be channelled as an effective tool for building knowledge and awareness. Furthermore, engaging local citizens in data collection can built adaptive learning, social capital, and encourage the ethos of stewardship and care of local ecosystems over the long term.

5.6.2.4 Broadening collaboration

Extending beyond traditional partners and seeking new collaborations in maintaining ecosystem services, and the design and implementation of nature-based approaches to adaptation will help to fuel innovation. In some cases, this may require overcoming barriers in communicating the value of biodiversity and ecosystem protection, particularly in terms of maintaining ecosystem services under a changing climate. The promotion of ecosystem services within the context of climate change adaptation measures could be tailored to different audiences using terminology that is familiar to them, while highlighting the relevance of these measures to target groups. The term “ecosystem services” is not understood by all, but the concept of deriving benefits from nature is widely recognized and is relatively easy to explain and connect to particular groups.

5.6.2.5 Innovative investments and partnerships

Innovative investments and partnerships are emerging for investments in nature-based approaches and the preservation of ecosystems and their services. For instance, the Government of Canada announced the $500 million Canada Nature Fund in late 2018, which will provide matching funds for provincial, territorial, municipal and NGO-led projects to achieve conservation goals. Other financing opportunities that blend public and private funds—such as green bonds, social finance models, and nature-based insurance mechanisms, among others—can be devised to provide needed investments in nature-based approaches and the preservation of ecosystems and their services. Major federal infrastructure funding also exists under the Disaster Mitigation and Adaptation Fund and the Adaptation, Resilience and Disaster Mitigation sub-stream of the federal Green Infrastructure Fund.

5.6.2.6 Growing private interest in nature-based approaches to adaptation

Globally, the private sector is increasingly acknowledging the importance of healthy and intact ecosystems. The World Economic Forum (2020) has listed biodiversity loss and environmental damage, failure to reduce GHG emissions and adapt to climate change, and extreme weather and natural disasters as the top three risks to the global economy over the past six years. Businesses are increasingly seeking enhanced understanding of operational risks, supply chain continuity, liability risks and market disruptions that could result from the loss and degradation of ecosystems and their associated services.

5.7 Conclusion

Climate change presents a multitude of risks, opportunities and trade-offs for Canada's ecosystems and the people that rely on them. The nature and severity of the impacts will depend on the rate and magnitude of climate changes in the years to come and in the success of adaptation measures. An improved understanding of the multiple drivers of change that affect ecosystem services, as well as the ways in which changes to ecosystem services affect communities and vulnerable segments of the population can help to target the most effective adaptation strategies. Natural systems can also play an important buffering role in terms of reducing the severity of climate change impacts. Nature-based approaches to adaptation have been shown to provide comprehensive, multi-disciplinary and flexible approaches that promote a suite of co-benefits, particularly compared with engineered approaches to adaptation. This is a rapidly growing field of interest and study in Canada, which promises to produce new knowledge and lessons learned in the years to come.

5.8 References

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5.9 Appendix 1

The following table was developed by the author team for this chapter and reflects their collective expert opinion on the ways in which climate change is affecting ecosystem services in Canada, the social and economic consequences of those impacts and related opportunities for nature-based approaches to adaptation and/or GHG emissions reduction.

Table 5.4: Ecosystem services, threats and opportunities

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
REGULATING CONTRIBUTIONS			
Maintenance of options (i.e., the ability of ecosystems to provide services and maintain options for present and future generations)	• Land-use change leading to loss of species and ecosystems, carbon storage • Degraded water sources	• Increased costs to society • Increased prevalence of disease • Limited options for future generation • Loss of local cultures, practices, languages and knowledge	• Protecting species and maintaining ecosystems (e.g., Indigenous Protected and Conserved Areas) • Ecosystem restoration

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
Climate regulation (i.e., the ability of ecosystems to sequester and store carbon)	• Land-use change and deforestation leading to reduced rates of carbon sequestration • Altered vector population dynamics • Impacts to water and food security • Reductions in biodiversity	• Loss of livelihoods (e.g., ecotourism, fishing and forestry) • Reduced water and food security • Economic losses associated with flooding, drought and loss of land • Emergence of climate refugees	• Green infrastructure • Reforestation and restoration of ecosystems • Climate friendly urban design, biomimicry
Regulation of freshwater quantity, flow and timing (i.e., the use of freshwater for domestic consumption, agriculture, industry, transportation and recreation)	• Changes to seasonal stability and timing of water supplies • Depletion of aquifers and base flows • Deglaciation • Loss of vegetative cover	• Increased reliance on technological solutions for water storage and transport • Impacts to human health • Impacts to livelihoods • Flooding and associated social, health, and economic costs	• Restoration of freshwater ecosystems • Improvements in efficiency of water use • Green infrastructure (e.g., creation of wetlands) • Decreasing impermeable surfaces • Increasing natural vegetation in urban and semi-urban areas

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
Regulation of freshwater and coastal water quality (i.e., delivery of high water quality for human consumption, biodiversity and economic development)	• Altered vector population dynamics • Increased prevalence of disease and pests • Land-use change in upland ecosystems • Contamination resulting from natural disasters including floods	• Impacts to public health • Increase of disease/ costs of health care from contaminated water. • Economic loss	• Maintaining upland ecosystems • Revise wastewater regulations to require tertiary treatment and resource recovery
Regulation of hazards and extreme events (i.e., biodiverse and healthy ecosystems reduce impact of fires, flood, landslides, drought and extreme heat)	• Loss of plant and animal communities • Reduction in long-term groundwater storage • Impacts of extreme heat, drought and fire to ecosystem functioning • Vulnerability of forest ecosystems to fire	• Mortality • Injury • Economic loss • Increased cost to society for mitigating hazards • Opportunity cost	• Green infrastructure to help buffer impacts of extreme events • Utilization of nature for refuge and recovery spaces after extreme events • Incentives to vacate flood areas and restore natural ecosystems instead of building dykes
Habitat creation and maintenance (i.e., sufficiently intact natural habitat to support biodiversity)	• Land-use change leading to loss of ecosystem services • Shifting species distribution ranges • Disturbance	• Opportunity cost • Reduction in population for species of cultural and economic importance to communities	• Increasing connectivity of ecosystems • Green infrastructure in urban areas • Connectivity across transportation routes

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
Regulation of air quality (i.e., the exchange of trace gasses and deposition of particulate matter by ecosystems)	• Reduced capacity to regulate from excessive pollution • Harvesting of forests	• Increased disease and mortality • Increasing healthcare costs	• Green infrastructure in urban areas to increase service (e.g., tree planting) • Reforestation and restoration of ecosystems
Regulation of organisms detrimental to humans (i.e., the contribution of biodiversity and ecosystems to human health)	• Habitat loss • Land-use change • Altered vector population dynamics • Increase in invasive alien species • Loss of biodiversity; shifts in species range	• Increased disease and mortality from extreme weather and water-borne diseases • Increasing healthcare costs • Economic loss	• Fostering greater biodiversity in all systems • Management of vector species
Pollination and dispersal of seeds and other propagules (i.e., the role of pollinator species in plant reproduction, food production and maintenance of terrestrial biodiversity)	• Habitat loss • Lack of diversity in systems • Environmental pollution • Introduction of alien species	• Economic loss • Loss of cultural traditions and diversity • Reduced food security • Loss of pollinated foods and medicinal plant crops	• Fostering greater biodiversity in all systems • Green infrastructure (e.g., to increase connectivity in systems, provide habitat and food sources) • Increase diversity in food systems

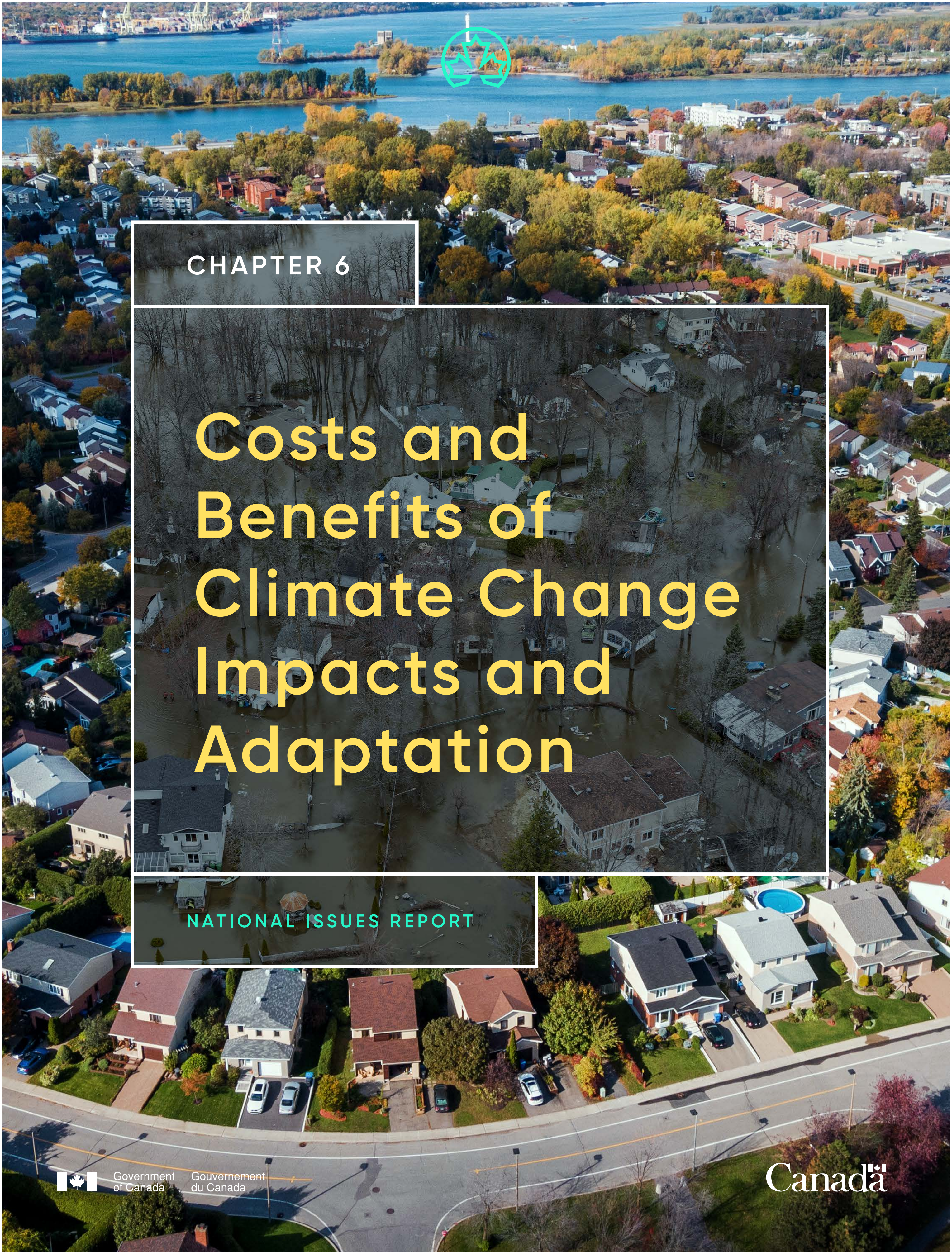
ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
Regulation of ocean acidification (i.e., the contribution of ocean ecosystems to climate regulation)	• Loss of coastal ecosystems leading to loss of mitigation opportunities • Environmental pollution • Introduction of alien species	• Economic loss (decrease in commercial and subsistence shellfish fisheries) • Reduction in coastal tourism • Loss of livelihoods and entire economies in some places	• Protection of coastal habitats
Formation, protection and decontamination of soils and sediments (i.e., the role of soil in the provision of water and nutrients for terrestrial vegetation; global carbon and nitrogen cycles)	• Land-use change contributing to soil loss and erosion • Loss of carbon storage • Reduction in quality and quantity of water	• Economic loss • Increased risk of disease by pests and pathogens • Food security (less nutritious foods) • Flooding and relocation related to sea level rise	• Soil biodiversity management practices • Low input agricultural practices

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
MATERIAL CONTRIBUTIONS			
Food and feed (e.g., crops, livestock, fisheries, aquaculture, wild foods)	• Competition for land, water and energy • Overexploitation • Availability of land with adequate climatic and soil conditions • Available sources of water for irrigation • Increased prevalence of pests and toxic contamination	• Loss of livelihoods and entire economies in some places • Reduced food security (from impacts on crops and fisheries) • Economic loss • Depression and reduced job security for workers	• Encouraging natural pest regulation • Managing regulating services for system resilience • Managing wetlands for flood control • Land-use management regulations that expand/retain areas for conservation and agricultural • Moving production further north when environmental requirements of species allow
Materials and assistance (e.g., timber and fibre for construction material, clothing and raw materials)	• Fire management • Soil degradation • Reduced water regulation and quality • Impeded carbon storage capacities • Overexploitation • Reduction in diversity of species • Compromised ecosystem integrity	• Loss of livelihoods and entire economies in some places • Loss of cultural traditions and diversity • Reduced security from increased fires	• Fire management • Natural pest management • Building Code requirements for timber construction

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
Energy (e.g., charcoal, hydropower, wind, biomass, solar power, geothermal)	• Increased reliance on renewable energy • Competition for land, water and energy • Impacts to biodiversity	• Impacts to food security and human health • Loss of livelihoods	
Medicinal, biochemical and genetic resources (e.g., medicines derived from biochemical and genetic resources)	• Climate-related biodiversity loss • Invasive species • Overexploitation	• Loss of cultural traditions and diversity • Impacts to human health • Risks associated with disease	
NON-MATERIAL CONTRIBUTIONS			
Learning and inspiration (i.e., nature-based opportunities for scientific research, art, restoration, and inspiration)	• Land-use change associated with urban areas • Overharvesting of resources • Loss of local cultures, practices	• Loss of culture, identity • Decrease in well-being	• Fostering greater biodiversity in all systems • Management focused on key ecosystems, biodiversity

ECOSYSTEM SERVICES	CLIMATE CHANGE THREATS TO ECOSYSTEM SERVICES	SOCIAL AND ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IMPACTS ON ECOSYSTEM SERVICES	OPPORTUNITIES FOR NATURE-BASED ADAPTATION AND/ OR GHG EMISSIONS REDUCTION
Supporting identities (i.e., physical places that are symbolic and/or that are a part of social relationships that form cultural identities)	• Loss of local cultures, practices, languages and knowledge • Restricted availability of local resources • Loss of biodiversity of significance	• Impacts to culture, identity, emotional and social well-being • Decrease in well-being; impacts to mental health • Loss of subsistence economy	• Social-ecological modelling to understand impacts of climate change on Identity • Indigenous Protected and Conserved Areas (IPCAs)
Physical and psychological experiences (i.e., the importance of nature to physical and mental health)	• Land-use change leading to lack of access to nature • Loss of local cultures, practices	• Impacts to culture, identity, emotional and social well-being	

Source: This table is based on the expert opinion of the author team.



CHAPTER 6

Costs and Benefits of Climate Change Impacts and Adaptation

NATIONAL ISSUES REPORT

Government of Canada Gouvernement du Canada

Canada

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Key messages

Economic analysis helps to inform adaptation planning (*see* Section 6.2)

Faced with limited resources and competing priorities, decision makers can use economic analysis to clarify trade-offs and make the case for allocating resources to specific adaptation actions by obtaining information on the costs and benefits of different options.

Climate change leads to a wide range of economic and social costs (*see* Section 6.3)

Climate change results in a wide range of direct and indirect costs, with numerous economic and social implications. Actions to adapt to climate change can deliver significant co-benefits in other areas, as well as result in unintended costs.

Costs related to extreme weather events are increasing (*see* Section 6.4)

Costs associated with damage from extreme weather events in Canada are significant and rising, largely due to growing exposure and increasing asset values. The scale of costs suggests that households, communities, businesses and infrastructure are not sufficiently adapted to current climate conditions and variability.

Future climate change costs for Canada will be high (*see* Section 6.5)

While climate change will present some benefits for Canada, the associated economic impacts are overwhelmingly negative. Much of the available evidence covers only a subset of the full extent of potential economic impacts from climate change for Canada. Projected costs are likely very conservative.

Economic decision support tools help with assessing adaptation options (*see* Section 6.6)

Economics offers a range of tools to help decision makers appraise adaptation actions, understand trade-offs and generate information on the costs and benefits of different options. The appropriate economic tool to use depends on the criteria for the adaptation decision, the nature of the climate change impacts and the level of uncertainty.

The benefits of adaptation actions in Canada outweigh the costs (*see* Section 6.7)

The benefits of planned actions to adapt to climate change in Canada generally exceed the costs, sometimes significantly, providing a strong business case for proactive investment in adaptation. Even when beneficial adaptations are adopted, residual damage costs are often still incurred, suggesting that there are economic limits to adaptation.

There are economic barriers and limits to adaptation (*see* Section 6.8)

There is a range of ecological, technological, economic and institutional barriers to adaptation, which limit the potential to reduce negative climate change impacts and benefit from new opportunities. Government can play an important role in addressing these barriers, although an economically efficient level of adaptation will likely involve some residual costs.

6.1 Introduction

6.1.1 Introduction

Climate change already results in economic impacts and will do so increasingly in the future. These impacts affect different aspects of the economy, public health and the natural environment. Assessing the economic impacts of climate change is a complex undertaking, with considerable uncertainties surrounding the magnitude of future biophysical impacts and the monetary value of those impacts. Notwithstanding these difficulties, economists have been examining the relationship between climate change and economic impacts for over 20 years. In 2011, for example, the National Round Table on the Environment and the Economy (NRTEE) estimated the average future cost of a high climate change–rapid growth scenario for Canada at $35–$62 billion (2019 dollars) annually by 2050, with a 5% chance that costs could exceed $72–$131 billion per year (NRTEE, 2011).

Information on the economic consequences of climate change, as well as on the costs and benefits of alternative courses of action, is increasingly being demanded by a wide range of private and public sector actors. This information is needed to inform resource allocation decisions in response to actual and projected climate change risks (National Research Council, 2010; 2009). Two generic response options are available: greenhouse gas (GHG) emissions reduction and adaptation measures (*see* Box 1.2 in Canada's Changing Climate Report)—an effective and efficient policy response will require a mix of both options. Indeed, from an economic perspective, the total costs associated with climate change can only be minimized through a combination of GHG emissions reduction and adaptation actions (e.g., Agrawala et al., 2011; de Bruin et al., 2009a).

The economics profession has historically been more focused on GHG emissions reduction (Fankhauser, 2017), although the number of studies on adaptation costs and benefits is increasing. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) dedicated an entire chapter to the economics of adaptation (Chambwera et al., 2014) and several other recent reviews have also focused on this subject (e.g., Kahn, 2016; Rouillard et al., 2016a; Markandya et al., 2014).

This chapter assesses the state of knowledge and practice on climate change impacts and adaptation economics in Canada. It focuses on answering the following questions: What do we know about the economic costs of climate change for Canada? What is the distribution of these costs across different regions, sectors and population centres? What are the costs and benefits of actions taken to moderate potential damages or to seize beneficial opportunities? And what economic tools and methodologies can be used by practitioners to address these questions? Decision makers need answers to these questions in order to allocate scarce public and private resources for climate change adaptation, and to ensure that these resources are directed towards the most efficient actions. This chapter will be of interest to a wide range of decision makers, economists and practitioners at all levels of government, and to businesses operating in climate-sensitive sectors.

6.1.2 Context

Over the last several decades, extreme weather events—such as wildfires, flooding, heat waves and storms—have caused billions of dollars in economic damages annually worldwide (Aon, 2020; Swiss Re Institute, 2020). Since 1980, cumulative damages worldwide have surpassed $4.9 trillion (2019 dollars)[1] (Munich RE, 2020); the U.S. alone has sustained about $2.2 trillion (2019 dollars) in damages resulting from 265 weather and climate disasters over the last 40 years (National Centers for Environmental Information, 2020). Over a similar period, damages in Canada totalled about $31 billion (2019 dollars) (Public Safety Canada, 2020). Inflation-adjusted damages have also been trending upwards—globally, regionally and in Canada (*see* Section 6.4.2; Aon, 2020; National Centers for Environmental Information, 2020; Insurance Bureau of Canada, 2019).

Climate change has increased the likelihood of certain types of extreme climate and weather events occurring (Zhang et al., 2019; National Academies of Sciences, Engineering and Medicine, 2016) and is expected to intensify some events in the future (Bush and Lemmen, 2019). Unabated climate change is projected to result in hundreds of trillions of dollars in economic damages globally in 2100 (Warren et al., 2018)—both from the intensification of certain climate extremes and from the impacts of slow-onset climate trends (e.g., processes like sea-level rise and melting of permafrost). A recent study, for example, suggests that a persistent increase in average global temperature of 0.04°C per year (consistent with a scenario of no major policy changes and continued GHG emissions) will reduce global economic output per capita by about 7.2% below where it would otherwise be in 2100; projected declines in per capita output in the U.S. and Canada are higher still, at 10.5% and 13.1%, respectively (Kahn et al., 2019).

Adaptation can significantly reduce the projected costs of climate change by billions of dollars per year (U.S. Global Change Research Program, 2018), though it is unlikely to entirely offset economic damages (*see* Section 6.8.2). Ambitious policies to reduce global GHG emissions are also needed to limit the negative impacts of climate change (OECD, 2015; Agrawala et al., 2011; de Bruin and Dellink, 2011; Wang and McCarl, 2011). However, adaptation is not costless. Globally, it is estimated that investment needs for climate change adaptation in industrialized countries will reach US $29–$138 billion (2019 dollars) per year by 2030 (UNFCCC, 2007). Adapting coastlines and water, transportation and energy infrastructure in the United States could cost tens to hundreds of billions of dollars annually by 2050 (Sussman et al., 2014). In Canada, an investment of just over $5 billion (2019 CAD dollars) will be needed annually, on average, over the next 50 years to adapt municipal infrastructure (buildings, facilities, roads, etc.) to climate change (Insurance Bureau of Canada and Federation of Canadian Municipalities, 2020). The exponential shape of adaptation cost curves suggests that initial levels of adaptation can be achieved at relatively low cost, but that costs could be substantially higher in the long term as increasingly less cost-effective actions are required to achieve greater levels of adaptation (Agrawala et al., 2011). Nevertheless, judicious adaptation decisions can yield benefits—in the form of avoided damages—that far exceed costs (Global Commission on Adaptation, 2019; Lempert et al., 2018).

Given the potential magnitude of investment costs for climate change adaptation in the short and long terms, there is a need to provide decision makers with reliable economic information on costs and associated benefits to support adaptation investment decisions. Decision makers—whether in the public or private sector—face limited human and financial resources. They will not be able to pursue every prospective program

1 Unless specified otherwise, all values presented in this chapter are in Canadian dollars (CAD).

or policy, and so must justify and set priorities for allocating available resources, including for climate change adaptation strategies and actions. In this regard, the field of economics can be of assistance, as it encompasses the study of how to efficiently allocate resources to meet desired goals. Specifically, economic analysis can help decision makers to weigh the costs of acting vs. the costs of inaction (i.e., continuing with a business-as-usual approach); to choose how much to invest in relation to competing priorities that are not climate-related; to decide which types of adaptation options, sectors and locations should receive resources; to balance near-term and long-term objectives; and, relatedly, to consider the impacts for future generations (Chambwera et al., 2014; National Research Council, 2010). Many adaptation benefits (i.e., avoided damages) will also deliver impacts in other areas, including health and safety, cultural heritage, ecosystem services and equity. Failure to include these types of non-market considerations in the decision-making process leads to underinvestments in adaptation. Economic analysis can be helpful in this regard as well, offering specialist techniques for capturing non-market climate change impacts in decision making.

6.2 Economic analysis helps to inform adaptation planning

Faced with limited resources and competing priorities, decision makers can use economic analysis to clarify trade-offs and make the case for allocating resources to specific adaptation actions by obtaining information on the costs and benefits of different options.

Information on the costs associated with climate change provides the impetus for action. Providing decision makers with the costs and benefits of adaptation informs the overall scale of investment in adaptation and the selection of specific measures. Economic analysis has evolved from focusing on cost-benefit analysis (CBA) to identify the "optimal" adaptation option towards providing tools to inform early action, with greater emphasis placed on the value of information, and the costs and benefits of capacity building and overcoming barriers to adaptation. Increasing emphasis is also being placed on the use of adaptive risk management frameworks and the need to better manage uncertainties.

6.2.1 Introduction

As decision makers become increasingly aware of the risks of climate change, there is growing demand for more effective ways to support adaptation decisions (Moss et al., 2014; National Research Council, 2010). The framing for adaptation planning has changed to meet these demands. With increased recognition of the need to manage uncertainty and develop practical early actions, there has been a shift towards a more policy-centric approach. Such an approach has the starting objective of climate change adaptation, as well as increased interest in the timing and sequencing of adaptation options, and the use of adaptive risk management frameworks for decision making (Rouillard et al., 2016a; Watkiss, 2015). These changes have important consequences for the use of economic analysis in informing adaptation decisions.

6.2.2 Entry points for economic analysis in risk management frameworks

Decision support in the context of climate change presents unparalleled challenges. Uncertainties associated with climate change—relating to how future social and economic systems will evolve; time lags between human activities and the response of the climate system; the dynamics of climate and biophysical systems; the diverse mix of potentially affected stakeholders; and autonomous adaptation by natural and human systems—make it hugely difficult to predict when and where climate change impacts will occur, as well as their relative importance (Chambwera et al., 2014; Jones et al., 2014; Heal and Millner, 2013). Regarding adaptation, these uncertainties are exacerbated at the regional and local levels, where many adaptation options are implemented. Adaptation decisions are complicated by further uncertainties relating to different stakeholder perspectives, multiple and competing objectives, long decision time frames, the choice of monetary values, and the broad range of adaptation options to select from (e.g., private or public, reactive or planned, stand-alone or integrated ("mainstreamed") (Rouillard et al., 2016a; Jones et al., 2014; Li et al., 2014; Randall et al., 2012).

Consideration of uncertainty is fundamental to adaptation decisions and related economic analyses. Given the multifaceted and uncertain nature of adaptation decisions, the consensus view is that such decisions are best considered in an adaptive (i.e., iterative) risk management framework (Lempert et al., 2018; Jones et al., 2014; Moss et al., 2014; IPCC, 2012; National Research Council, 2010).

Adaptive risk management provides a framework in which potentially significant, but uncertain, consequences of current and future climate change and adaptation actions are continually identified, assessed, prioritized, managed and revised; this framework includes monitoring, which takes into account new information, experience and stakeholder input (Lempert et al., 2018; National Research Council, 2010). It entails an ongoing cycle of assessment, action, reassessment and response that will continue in perpetuity, rather than informing one-off decisions at a single point in time (Lempert et al., 2018; Willows and Connell, 2003). The National Research Council (2010) draws an analogy with decisions in a chess game, where pieces are repositioned and risk is reassessed in response to the opponent's moves.

From an economic analysis perspective, adaptive risk management provides a useful framework for adaptation decision making. It allows for the use of a broad range of concepts, processes and decision support tools—including traditional tools like cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria decision analysis (MCDA) (*see* Table 6.4), as well as tools that are more adept at accommodating deep uncertainties, such as robust analysis and dynamic adaptation pathways (*see* Figure 6.3; Table 6.4; Moss et al., 2014). Importantly, adaptive risk management allows decision makers to consider a broad range of criteria (e.g., costs, benefits, co-benefits and co-impacts (*see* Section 6.3.4), equity, affordability, flexibility, robustness, etc.) when formulating adaptation strategies in the face of uncertainty (*see* Section 6.6.1).

The awareness, assessment and planning stages of a generalized adaptive risk management framework provide specific entry points for economic information, analysis and decision support (*see* Figure 6.1). During the awareness raising stage, information on the costs of inaction (i.e., the net cost reflecting the difference between economic damages and any beneficial opportunities arising from climate change) can be used to persuade decision makers of the need and urgency to allocate resources to adaptation planning. This information may include estimates of the scale of climate-related costs; the distribution of those costs across locations, sectors, population groups, etc.; and the time frame over which they are projected to become significant, if they are not already so. The same information can also be used by analysts and stakeholders to inform the prioritization of current and future climate risks and vulnerabilities during the assessment stage. Economic analysis also plays an important role during the planning stage, where it can be used to inform the overall scale of investment in adaptation; the selection, timing and sequencing of specific adaptation options; as well as the distribution of adaptation costs and benefits.

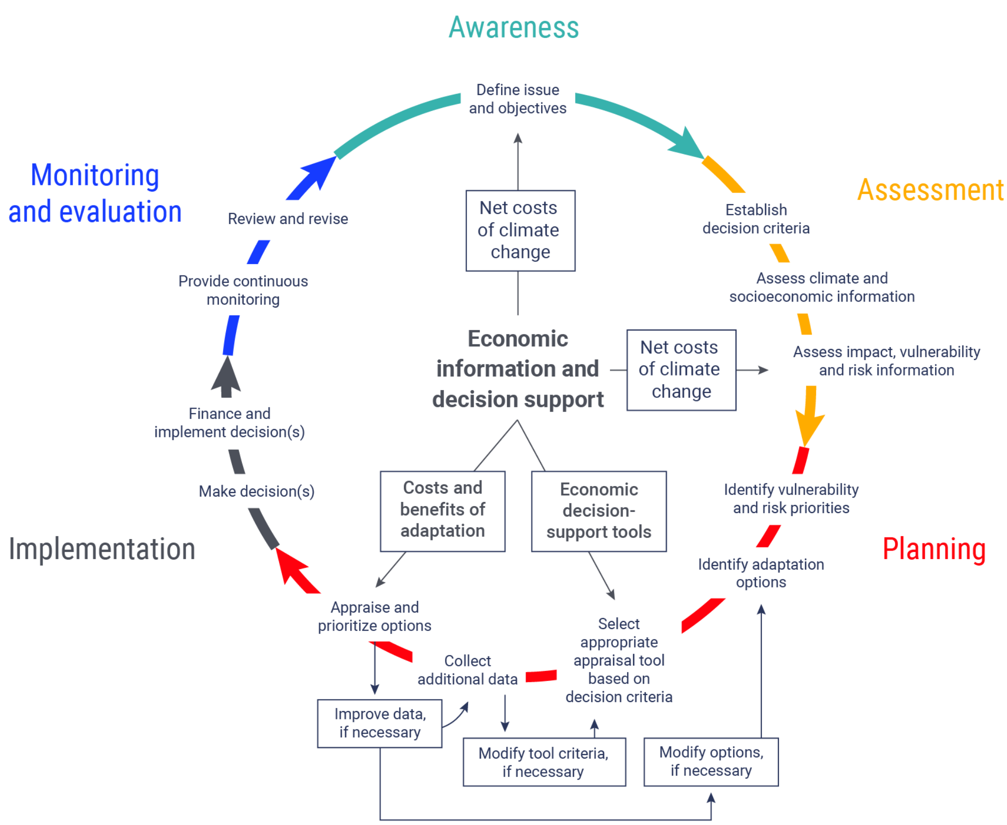


Figure 6.1: The generalized adaptive risk management framework for climate change adaptation comprises five stages: 1) awareness, 2) assessment, 3) planning, 4) implementation and 5) monitoring and evaluation. Not all feedback loops are shown in the figure for ease of presentation (e.g., between planning and awareness, and between planning and assessment). Source: Adapted from Lempert et al., 2018; Rouillard et al., 2016a; and Meyer et al., 2015.

6.2.3 Shift towards policy-centric adaptation planning

The assessment and planning stages of an adaptive risk management framework are typically navigated following one of two generic analytical processes (Jones et al., 2014). Historically, the predominant approach is based on a “science-first” (also known as “top-down”, “scenario-led” and “predict-then-act”) impact assessment-driven process (Gregory et al., 2012; Wilby, 2012; Ranger et al., 2010). This involves first defining impact pathways—climate change projections combined with socioeconomic information to assess future risks and costs—using impact models or damage functions (i.e., an empirical relationship characterizing the predicted change in monetary damages that is attributable to a change in a climate variable or index). The range of estimated risks is then used to frame the selection of adaptation options. Identified options are appraised as a final step in the process to determine the desired adaptation level, which is informed by adaptation costs, benefits and residual costs (i.e., the monetary damages attributable to climate change that will remain after adaptation) (Watkiss, 2015). With this approach, however, uncertainty is compounded at each stage of the analytical process (*see* Figure 6.2) and is seldom adequately characterized (Wilby, 2012). In the presence of such ballooning uncertainties, the range of plausible impacts and adaptation responses can become unworkable, rendering the “science-first” approach impractical (Dessai et al., 2009; Dessai et al., 2005). Further issues with the “science-first” process include the following: it does not adequately address non-climate drivers of impacts and risks; its long-term focus does not align with immediate policy needs to inform near-term adaptation decisions; it fails to consider the adaptation process itself and ignores potential barriers, transaction costs and baseline policies; and it tends to emphasize “hard” (i.e., engineered) adaptation options over “soft” options, like building adaptive capacity (Rouillard et al., 2016a; Watkiss, 2015; Patt et al., 2010).

Given the shortcomings of the “science-first” approach, there has been a shift in adaptation practice towards “policy-first” analytical processes (Rouillard et al., 2016a; Watkiss, 2015; Watkiss et al., 2015a; Downing, 2012). “Policy-first” approaches—also known as “bottom-up”, “assess-risk-of-policy” and “decision-centric” approaches (Pielke et al., 2012; Brown et al., 2011; Ranger et al., 2010; Dessai and Hulme, 2007)—place greater emphasis on adaptation as the starting objective, rather than considering it as the final step, which is usually the case in a traditional “science-first” impact assessment. With the “policy-first” approach, a significant amount of effort is devoted at the outset to characterizing the decision problem (e.g., a flood risk management plan). This includes first identifying relevant objectives, current practices, constraints and drivers of change, as well as stakeholder preferences and related decision criteria, all of which frame subsequent analyses. Next, the process involves assessing the vulnerability of the defined system to current climate, socioeconomic and policy conditions, before considering sensitivities to future stressors, including climate and non-climate related stressors (Ranger et al., 2010). Once the limitations of current practices are understood, alternative options are identified if necessary and assessed with respect to achieving the stated objectives across a range of plausible future scenarios. For instance, the Thames Estuary 2100 Project in London, U.K., (*see* Case Story 6.4) was one of the first large-scale infrastructure projects to adopt a “policy-first” approach to adaptation planning (Ranger et al., 2013).

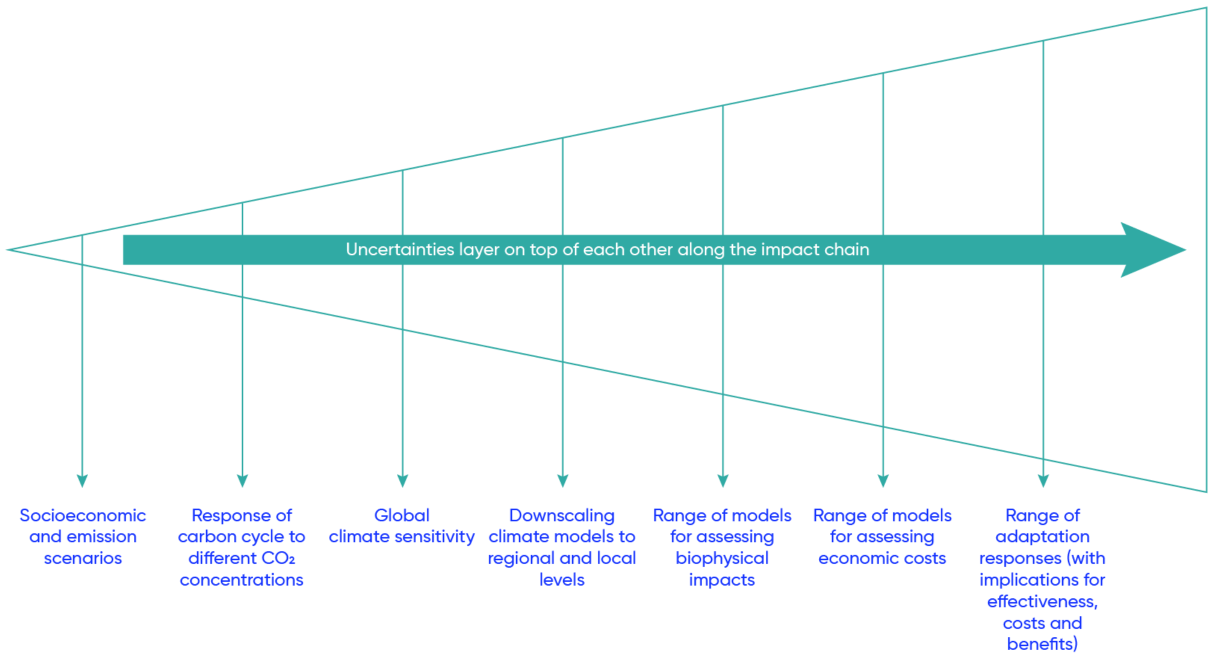


Figure 6.2: Illustration of ballooning uncertainties along a "science-first" causal impact chain. The level of uncertainty increases as one moves along the impact chain (from left to right), leading to a high level of uncertainty in the cost and benefit estimates at the end of the chain. Source: Adapted from Fussel, 2003.

Compared to the classic "science-first" approach, the "policy-first" approach has a number of advantages (Gregory et al., 2012; Pielke et al., 2012; Brown et al., 2011; Ranger et al., 2010; Wilby and Dessai, 2010; Dessai et al., 2009). For example, because the "policy-first" approach requires only climate information pertinent to the decision problem at hand and focuses the assessment on adaptation options that are acceptable given the objectives and constraints of a particular decision, the analysis is streamlined and targeted from the outset, which makes it less resource- and data-intensive, as well as less sensitive to ballooning uncertainties. Furthermore, because the analysis is context-driven and not unduly influenced by scientific modelling, it emphasizes "big picture thinking" and encourages decision makers to consider interactions with broader policy priorities and to seek adaptation options that deliver co-benefits with other policy areas.

6.2.4 Focus on early adaptation and the timing and sequencing of options

Alongside the shift towards a "policy-first" approach and the use of adaptive risk management frameworks, increased consideration is also being given to the timing and sequencing of adaptation as a further means to manage uncertainties (Wise et al., 2014). There has been a move away from viewing adaptation as comprising one single response (e.g., a wall to reduce future flood risk). Instead, there has been a shift towards viewing adaptation as a coherent package of options to address current vulnerabilities and to prepare for medium- and long-term climate change risks, with a focus on practical early implementation (Rouillard et al., 2016a; Watkiss, 2015). Packages of options will typically comprise three types of activities or building blocks for early action (Rouillard et al., 2016a; Watkiss, 2015; Watkiss et al., 2014):

1. **Actions to address the existing adaptation deficit:** Immediate adaptation options that address risks arising today from current weather and climate extremes and, in so doing, also build resilience to future climate change. This would include “win-win”, “no-regret” and “low-regret” adaptation options that provide clear, immediate benefits or co-benefits.
2. **Actions to adapt decisions with long lifespans:** Adaptations that are mainstreamed into near-term decisions that have long lifetimes (e.g., decisions relating to climate-sensitive infrastructure or land-use planning), and thus will be influenced by future climate conditions and future risks, in addition to current conditions. In contrast to the previous category, uncertainty over future benefits is a much bigger concern. As a result, greater emphasis is placed on using robust options (i.e., actions that provide future benefits under a range of plausible future scenarios) and flexible strategies that provide opportunities for learning, with options that can be delayed or brought forward, and/or scaled up or down as new information emerges over time.
3. **Actions to support long-term adaptation:** This includes activities such as monitoring, surveillance, research and engagement, which immediately start building the capacity needed to support future actions to manage long-term climate impacts and risks. Examples include generating better information—which is required to inform later decisions about managing major, highly uncertain long-term risks—and actions that are needed to create a suitable policy and socio-cultural environment to enable and ensure that future options are still possible.

When viewed collectively as an integrated adaptation strategy, these three building blocks form a dynamic adaptation pathway (Haasnoot et al., 2018; 2013), as shown in Figure 6.3..

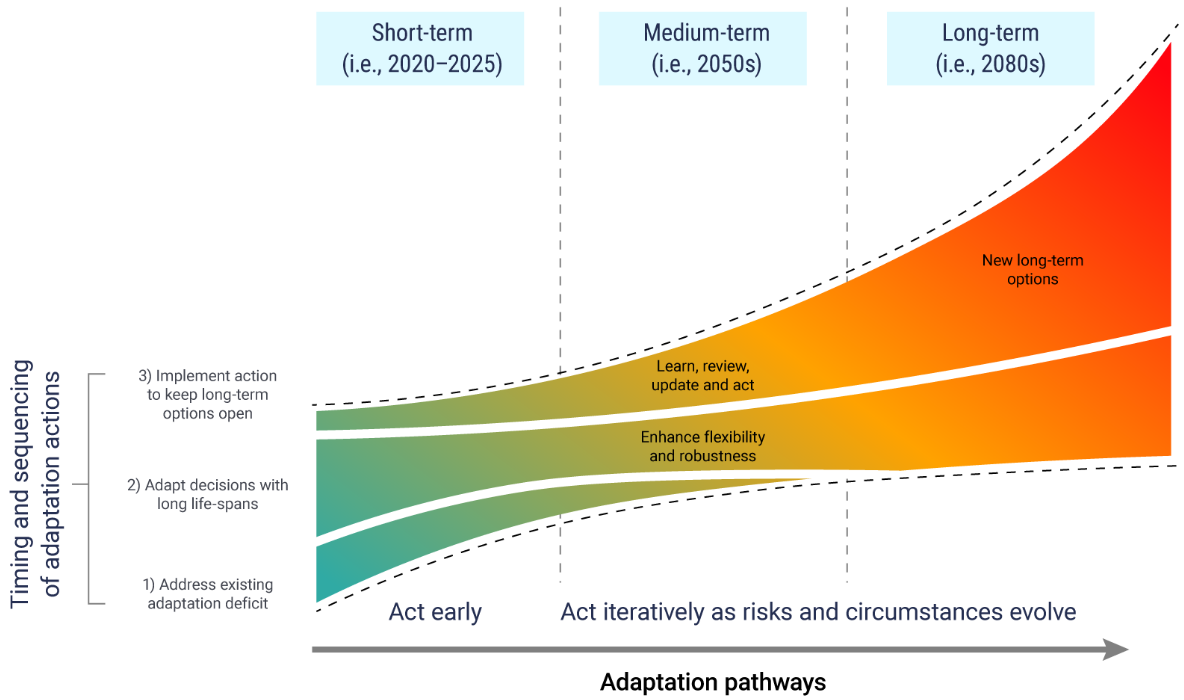


Figure 6.3: Illustration of the timing and sequencing of adaptation options within short, medium and long time frames along an adaptation pathway. Source: Adapted from Watkiss et al., 2014.

6.2.5 Implications of changing practices for economic analysis

The shift towards a "policy-first" assessment process, coupled with greater emphasis on the timing and sequencing of adaptation, and use of adaptive risk management frameworks, has had significant implications for the economic analysis of adaptation strategies. Mainly, these changing practices have necessitated the development, application and refinement of alternative decision support tools. Traditional economic decision support tools (e.g., CBA, CEA) are adequate for appraising early actions to address the existing adaptation deficit, where uncertainty over future impacts is less of a concern. However, for mainstreaming adaptation into decisions with long lifespans—where consideration of climate and non-climate-related uncertainties over future drivers of change is much more important, and where decision makers are thus looking for robust options or flexible strategies—alternative economic decision support tools like real options analysis, robust decision making, portfolio analysis and dynamic adaptation pathways are more appropriate for appraising options (*see* Table 6.5). Use of these tools globally in a climate change adaptation context is still in its infancy, and they have yet to be formally applied in Canada (*see* Section 6.7.1).

Further consequences of these changing practices for the economic analysis of adaptation include:

- With greater importance being placed on 1) mainstreaming and understanding the process of adaptation (including barriers to action), and 2) capacity building to ensure that long-term adaptation options remain possible (such as research, monitoring and institutional strengthening), there is an increasing need to assess the costs and benefits of non-technical options, including behavioural interventions to overcome barriers to change, and the value of information collated through monitoring systems. The characteristics of these options are different from those of outcome-based or engineered actions, with costs and benefits that are more challenging to measure and to include in economic analysis.
- Likewise, the increased emphasis on no-regret and low-regret adaptation options places greater importance on the need to fully capture co-benefits in the economic analysis, which requires the monetization of a broader range of non-climate impacts, in addition to avoided climate-related damages.
- Viewing adaptation strategies as a set of time-sequenced activities presents challenges for economic analysis, since each building block is unique and may require different information and methods for the quantification and valuation of physical impacts, and may entail resource implications for the analysis.
- All economic analyses typically need to consider trade-offs between early costs and future benefits, rendering the results sensitive to the discounting process and choice of discount rate (*see* Section 6.6.3.2). Analysis of actions to address the current adaptation deficit will generally be less sensitive to discounting assumptions. However, for early actions to adapt long-life decisions and keep long-term options open over many decades, outcomes will be more sensitive to the discounting of future benefits, making it essential to consider alternative and inter-generational discounting practices.

6.3 Climate change leads to a wide range of economic and social costs

Climate change results in a wide range of direct and indirect costs, with numerous economic and social implications. Actions to adapt to climate change can deliver significant co-benefits in other areas, as well as result in unintended costs.

There is a wide spectrum of terms used to characterize the economic consequences of climate change impacts, including direct costs (e.g., damage from a flooding event) and indirect costs (e.g., disruption in service delivery), macroeconomic impacts (e.g., reduction in gross domestic product (GDP) growth) and losses in the welfare of affected populations. Adaptation actions can result in a range of co-benefits in other areas, but can also lead to unintended costs. The range of terms used in the literature—many of which overlap and are sometimes used interchangeably—can lead to confusion among practitioners and decision makers, and can also impede efforts to compare the estimated costs and benefits of different adaptation actions.

This section describes key cost and benefit terms as they are used in the remainder of this chapter, based on common definitions from the literature.

6.3.1 Direct and indirect costs

Typologies of the economic consequences of climate change impacts—specifically impacts arising from extreme events—often distinguish between direct and indirect impacts, similar to the literature on natural disaster impacts. Direct and indirect impacts can be negative or positive, giving rise to costs (i.e., from losses or damages) or benefits (i.e., gains), respectively. This section refers solely to costs, although it applies equally to benefits.

Direct costs arise from the physical impacts of climate hazards, such as damage or disruption to tangible goods and services that can be traded in a market and thus have an observed price (e.g., costs incurred to repair or replace damaged homes, medical treatment costs for heat stress, lost revenue from reduced crop yields, etc.). Direct costs also arise from physical impacts to intangible items not bought or sold in a traditional market and thus having no readily observable price (e.g., ecosystem services, stress or pain levels, and general quality of life). Economists have developed multiple techniques to allocate a "shadow price"—an estimated price for a good or service whose market price does not accurately reflect its actual value or for which no market price exists—to these intangible items, which are referred to as non-market impacts. When non-market impacts are rendered equivalent to market impacts using shadow prices, they can be substantial—perhaps larger than market costs (Nordhaus and Boyer, 2000). Omitting relevant non-market impacts from the economic analysis of adaptation strategies could substantially bias the outcomes.

Indirect costs stem from direct climate change impacts. When infrastructure, a building or a park is damaged or destroyed, this can interrupt normal use or service flows (e.g., a flooded shop may have to temporarily close for repairs). Damaged infrastructure may result in disruption to the delivery of critical services (e.g., electricity, water, sanitation), which may interrupt the operations of businesses that are not directly affected by climate hazards. Workers may also not be able to get to work if road networks or transit infrastructure have been affected. These impacts are referred to as business interruption costs (Kousky, 2012). Interactions between businesses may in turn result in secondary or multiplier impacts through the economy (e.g., a flooded shop that closed its doors for repairs will not need to purchase supplies until it reopens). Like direct costs, indirect losses can also be divided into market costs (e.g., business interruption costs) and non-market costs (e.g., delayed illnesses and mental health disorders, increased inequality, etc.). In contrast to direct costs, indirect costs often span a longer time period and take place over a wider spatial scale than the site of the direct physical impacts of climate change (Hallegatte, 2013).

The sum of all relevant direct and indirect, market and non-market costs provides one measure of the total economic impact of climate change. Interest often focuses on the overall net result—the sum of potentially positive and negative impacts—and whether climate change produces net costs or net benefits.

6.3.2 Macroeconomic costs

If the sum of direct and indirect market costs is sufficiently significant, it may impact macroeconomic indicators, such as consumer and producer price inflation, the unemployment rate and GDP. GDP measures the value of output in an economy, part of which reflects investment and part of which reflects consumption. The GDP impacts of climate change can be estimated directly using computable general equilibrium (CGE) models—large-scale numerical models that simulate the main economic interactions (e.g., those between different product markets) in an economy—or through supply and use tables available from Statistics Canada that capture all relevant direct and indirect market costs. Projected changes in macroeconomic indicators, like GDP, should be used only as a supplementary lens through which to view the economic consequences of climate change. Macroeconomic indicators capture the aggregated direct and indirect climate change impacts on the economy. Macroeconomic impacts, if estimated directly, should not be added to other estimates of direct and indirect market costs, as this would entail double counting (Ratti, 2017; Kousky, 2012). At the same time, focusing solely on aggregate macroeconomic indicators like GDP can be misleading from a distributional perspective. The spatial scale of an extreme weather event can be different from the scale over which GDP is measured. Significant losses for local populations may have no visible impact on national GDP, or even on provincial or territorial GDP. However, this does not imply that the impacts are negligible for the people who are affected. This particularly applies to disadvantaged populations or locations, whose economic output is generally invisible in aggregate macroeconomic indicators. A further distributional issue regarding the spatial scale of climate change impacts and the use of aggregate macroeconomic indicators is that losses at one location can be offset by gains at another.

6.3.3 Welfare losses

The theoretically correct measure of the economic consequences of climate change is the resultant change in the welfare of affected populations (Kousky, 2012; Stern, 2006; Nordhaus and Boyer, 2000). Estimating changes in a theoretical metric like welfare is nonetheless difficult in practice. Consequently, GDP is often used as a practical, though far from perfect, proxy for welfare (Diaz and Moore, 2017a, b; Jones and Klenow, 2016). In addition to the aforementioned problems with using GDP to measure climate change costs, GDP only captures the value of impacts to market goods and services. As noted above, non-market impacts can be substantial—perhaps larger than market costs. Failure to account for non-market impacts will lead to seriously underestimating welfare losses. The output of the economy, as measured by GDP, also does not directly affect the welfare of individuals—what matters most to people is consumption and the loss of consumer surplus (Hallegatte, 2013). In the aftermath of extreme events, GDP can increase as the amount of investment increases to repair damaged assets—while this might suggest an increase in welfare based on the above definition, welfare will actually fall since households are foregoing consumption that they would otherwise have enjoyed in favour of investment. As a result, a more appropriate proxy for welfare costs resulting from climate change is a measure of consumption loss, rather than output loss as measured by GDP. Notwithstanding these concerns, the welfare costs of climate change in monetary terms are sometimes expressed as a percentage of projected GDP, referred to as a GDP-equivalent impact (Vivid Economic, 2013).

6.3.4 Co-benefits and other co-impacts

When making adaptation decisions, it is essential to consider another category of impacts that are important from an economic perspective and are referred to as “co-impacts”—these are more commonly referred to as “co-benefits” when the impacts are positive. In addition to applicable lifecycle costs and avoided climate-related damages, adaptation options can give rise to various ancillary impacts of potential significance, known as co-impacts (Chambwera et al., 2014). Recognizing co-impacts in adaptation decisions is important, as evidence suggests that people are more likely to act on climate change if the related impacts associated with specific actions are highlighted (Bain et al., 2015).

Many different terms are used with reference to co-impacts, depending on whether they are positive or negative, and intentional or unintentional (Floater et al., 2016; Urge-Vorsatz et al., 2014). Intentionality refers to the degree to which co-benefits are explicitly pursued by the decision maker, as early no-regret and low-regret adaptation options are prioritized to manage uncertainty (*see* Section 6.2.3). In addition to avoiding climate-related damages, adaptation options can contribute to GHG emissions reduction and other non-climate policy objectives related to issues such as economic development, public health, sustainability and equity. Avoiding climate-related damages can be the secondary objective of GHG emissions reduction or non-climate policies, or can serve as one of a number of objectives to be pursued simultaneously as part of a coherent, integrated package of policies (Floater et al., 2016). For example, the use of green roofs in cities as a strategy for reducing urban heat also helps to manage storm water, sequester carbon and improve urban biodiversity. In this case, using green infrastructure to address the adverse health effects of heat waves also contributes to the co-benefits of reducing GHG emissions, flood management, and the delivery of ecological services (*see* Case Story 6.1).

A range of terms are used to describe negative co-impacts—which are treated as unintentional—including co-costs, ancillary costs, adverse side-effects and externalities (Urge-Vorsatz et al., 2014). Examples of negative co-impacts generated by adaptation options would include increasing GHG emissions, increasing risks to other groups or sectors that are not targeted by the option, or limiting future adaptation choices.

6.3.5 Private and social costs

The final set of economic terms commonly encountered in the literature relates to the perspective adopted by the decision maker for appraising adaptation options. The costs and benefits of adaptation options can be assessed from a social, as well as a private, perspective (Halsnæs et al., 2007). From a social perspective, where a public policymaker is looking for a socially optimal allocation of resources to climate change adaptation, the appraisal of adaptation options should consider co-benefits, as well as potential negative consequences alongside estimated lifecycle costs and avoided damages (Floater et al., 2016; Chambwera et al., 2014). In contrast, households and businesses will be interested in a narrower set of private costs and benefits when making adaptation decisions—specifically, those costs and benefits that accrue to the individual decision maker. These private costs and benefits (sometimes referred to as financial impacts) are typically based on actual market prices. To understand the importance of the difference between the two perspectives, consider, for example, a home damaged by a flood event, where some direct costs are reimbursed through the Government of Canada's Disaster Financial Assistance Arrangements (DFAA) program. The private cost of the event to the homeowner is the difference between the repair costs incurred (not covered by private insurance) and the amount of aid received from the government. However, from the perspective of society, the aid represents a transfer payment from one taxpayer (a loss) to another (an equivalent gain); the loss and gain cancel each other out, leaving the full cost of repairs as a measure of the social cost of the flood event.

Case Story 6.1: Climate action by cities around the world is resulting in co-benefits

In 2015, the Economics of Green Cities Programme at the London School of Economics in the U.K. published a working paper called "Co-benefits of urban climate action: A framework for cities" that includes a literature review of the state of knowledge regarding urban co-benefits for climate action, based on a review of actions by cities around the world (Floater et al., 2016).

Overall, 116 co-benefits from 34 policy actions with a climate change adaptation focus were identified across 13 key urban sectors. The highest number of economic co-benefits from adaptation-related policies occurred in the health, land use and buildings sectors, and the highest number of social co-benefits generated from adaptation-related policies were recorded in the land use, Health and education sectors. The highest number of environmental co-benefits from these policies was observed in the land use, water and food security sectors. Generally, climate change adaptation policies in the land use and health sectors were found to generate the largest number of co-benefits.

Policies in other urban sectors were also found to generate co-benefits for climate change adaptation, GHG emissions reduction or both. Relatively high numbers of adaptation co-benefits were associated with policies in the following sectors: disaster and emergency management; food security; and tourism, culture and sport. Both climate change adaptation and GHG emissions reduction co-benefits were relatively strong for policies in the land use, health, water and education sectors.

6.4 Costs related to extreme weather events are increasing

Costs associated with damage from extreme weather events in Canada are significant and rising, largely due to growing exposure and increasing asset values. The scale of costs suggests that households, communities, businesses and infrastructure are not sufficiently adapted to current climate conditions and variability.

The number of extreme events has increased since 1983, although the distribution of these events across Canada varies significantly, with Alberta being affected the most. Studies on the attribution of such events in Canada indicate that climate change is increasing the likelihood of certain types of extreme weather events, and may be playing a role in the trend of growing losses from such events. However, the majority of rising losses related to extreme weather events are the result of growing exposure and rising asset values. The scale of costs suggests that there is an adaptation gap or deficit, whereby households, communities, businesses and infrastructure are not sufficiently adapted to current climate conditions and variability.

6.4.1 Introduction

Prior to reviewing evidence of the projected economic consequences of climate change for Canada, information on the costs of past severe climate and weather events is presented for context. Extreme events—such as heat waves, drought, flooding or strong storms—have the potential to cause extensive damage and impacts to people, buildings, infrastructure and the natural environment; severe weather causes tens of billions of dollars of damage each year worldwide (Aon, 2020; Swiss Re Institute, 2020). It is anticipated that climate change will intensify some types of extreme weather events in the future (Bush and Lemmen, 2019) and will contribute to rising damages in the coming decades. As a result, an appreciation of current vulnerabilities and gaps in preparedness in Canada is a good starting point for building a robust case for early action for climate change adaptation (*see* Section 6.2.3).

This section focuses on a single line of evidence—damages associated with weather extremes in Canada, as documented by the insurance industry. While extreme events might be the face of climate change, gradual trends in Canada's climate (e.g., rising mean annual and seasonal temperatures, rising sea levels, melting glaciers and permafrost, etc.) may also be leading to impacts with important economic consequences, including recent problems with mountain pine beetle infestations in B.C. (Withey et al., 2015) and the spread of Lyme disease vectors (Ebi et al., 2017). Compared to the impacts of extreme weather events, evidence of the economic consequences of these slow-onset impacts is sparse. The information presented in this section provides only a partial picture of the economic costs of past climate-related hazards in Canada, recognizing that current risks from weather extremes are significant and rising, and warrant early action.

6.4.2 Global trends in damages

The insurance industry is a key source of information on the economic consequences of weather extremes. Large reinsurers, such as Munich RE and Swiss Re, monitor and record information on losses from natural catastrophes globally to evaluate the capacity of national and international reinsurance markets to absorb losses (*see* Box 6.1 for a description of key insurance industry terminology).

Box 6.1: Commonly used insurance industry terminology

Economic losses represent the financial costs directly attributable to a natural disaster, such as damage to building structures and contents, infrastructure and vehicles, as well as losses due to business interruption as a direct consequence of damage to buildings. Economic losses include insured losses (i.e., economic losses = insured losses + uninsured losses). Economic losses do not, however, include indirect (i.e., ripple, secondary or multiplier) losses that result from the upstream or downstream disruption to the flow of goods and services as a result of damage to buildings, infrastructure, vehicles, etc. They also do not include non-financial impacts, such as impaired quality of life or loss of reputation.

A natural disaster or catastrophe is an event caused by natural forces. Weather-related natural disasters include hydrological (e.g., flooding), meteorological (e.g., storms, wind, hail, lightning, tornado, tropical cyclone) and climatological events (e.g., wildfires, extreme heat), but exclude geophysical events (e.g., earthquakes, volcanoes).

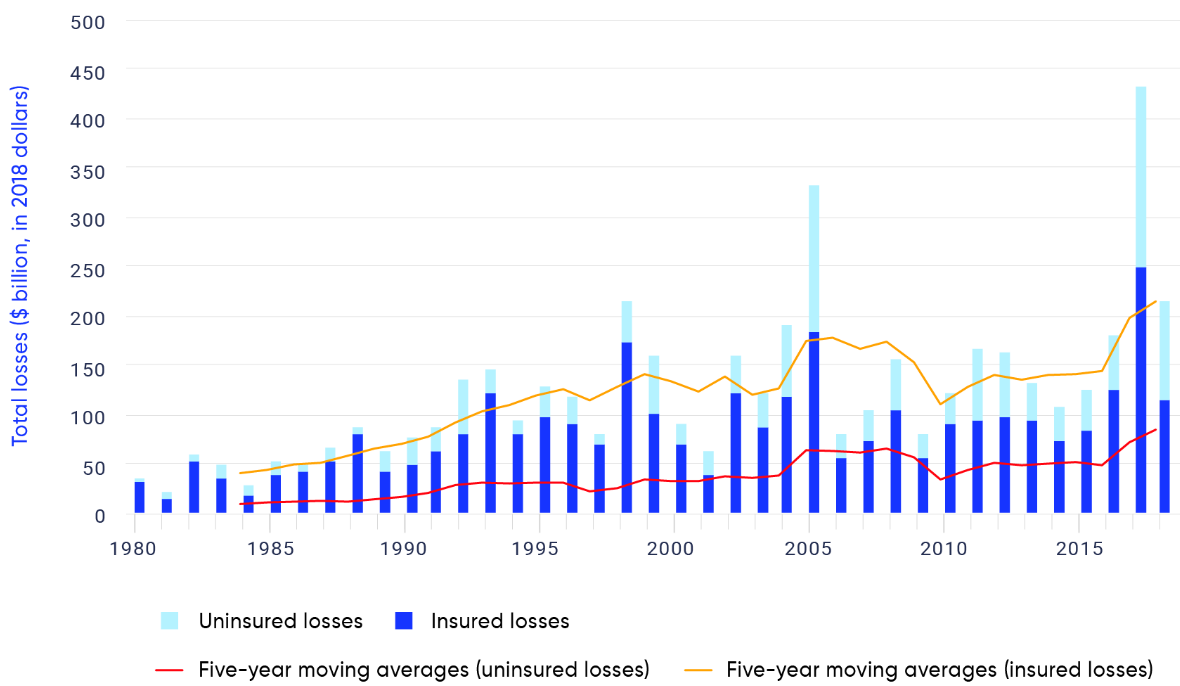
Source: Munich RE, 2018; Swiss Re Institute, 2018.

In 2018, weather-related natural disasters globally caused total economic losses of about $215 billion (2018 dollars USD), of which private insurers paid out a record $100 billion in losses (Munich RE, 2020). The global protection gap—the difference between insured losses and total losses—was therefore $115 billion (54% of total economic losses). These figures are similar to those produced by the Swiss Re Institute for 2018; estimated total economic losses and insured losses from weather-related natural disasters globally were, respectively, about $201 billion and $98 billion (2018 dollars USD), making the protection gap about $103 billion (or 51% of total economic losses) (Swiss Re Institute, 2019a). Both economic losses and insured losses in 2018 were higher than the corresponding inflation-adjusted annual average for the last ten years (2008–2018), which are $174 billion and $65 billion, respectively (Munich RE, 2020).

Globally, economic losses from natural disasters are rising. Overall losses and insured losses have been trending upward over the last several decades; this is evident in Figure 6.4, which shows worldwide loss data for the period 1980–2018 as recorded by Munich RE, the world's largest reinsurance company. Loss data recorded by the Swiss Re Institute also shows rising economic damages from weather-related natural disasters worldwide (Swiss Re Institute, 2019a). In terms of five-year moving averages, overall losses recorded by Munich RE grew by 5.1% annually between 1980 and 2018, and insured losses grew by 4.3% annually. With growth in overall economic losses outpacing insured losses, the protection gap has risen in absolute dollar terms over time, although the gap is falling in percentage terms. Despite increasing penetration of relevant insurance products with a greater proportion of damages covered by insurance (Swiss Re Institute, 2019a), society is absorbing increasing residual losses from weather-related natural disasters.

Economic losses from natural disasters affecting the U.S. are also rising (e.g., National Centers for Environmental Information, 2020). For example, the frequency of billion-dollar disasters between 1980 and 2011 increased at about 5% per year (Smith and Katz, 2013). During the period of 1980–2019, the U.S. experienced, on average, 6.6 events annually; over the most recent 5 year period (2015–2019), the annual average number of billion-dollar disasters was roughly double, at 13.8 events (National Centers for Environmental Information, 2020).

a)



b)

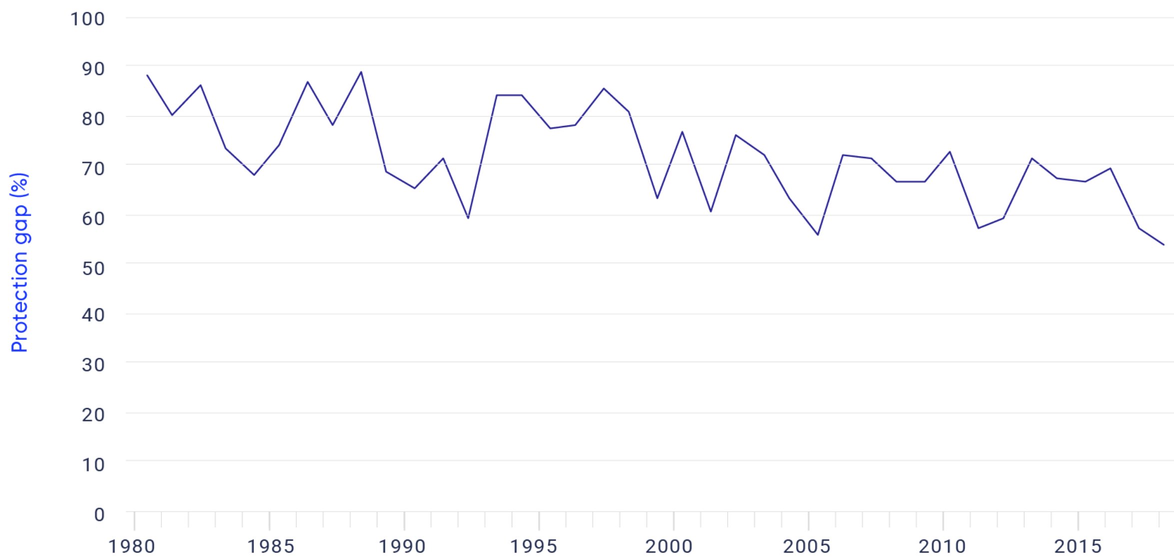


Figure 6.4: The figure shows annual insured and uninsured losses (in 2018 Canadian dollars) from 15,788 weather-related events (e.g., flooding, storms, wildfires, extreme heat, etc.) worldwide that meet Munich RE's NatCatSERVICE inclusion thresholds for dollar losses and fatalities over the period 1980–2017. a) The dark blue bars indicate the total insured losses and the light blue bars indicate the total uninsured losses from all weather-related loss events globally in each year. The combined light blue and dark blue bars indicate the total economic losses from all weather-related loss events globally in each year. b) This figure illustrates the "protection gap"—the proportion of insured losses compared with total economic losses—highlighting the economic loss generated by catastrophes that are not covered by insurance. Data source: Munich RE, 2020.

6.4.3 Damage trends in Canada

Public Safety Canada's Canadian Disaster Database (CDD) monitors overall economic losses from significant meteorological and hydrological disasters, including payments made under the DFAA program (*see* below) and those made by private insurers. The Insurance Bureau of Canada (IBC) also tracks private insurance payouts for extreme weather events dating back to 1983. However, data on overall losses in the CDD seems incomplete considering that, in over half of the years since 1983, insured losses recorded by the IBC exceeded total economic losses in the CDD. Due to the incomplete nature of the economic loss data, the narrative below focuses only on insured losses. If the U.S. can be considered to provide a reasonable analogy for Canada, overall losses from weather extremes are roughly double the amount of the insured losses (Aon, 2020).

Insured losses in Canada have been rising since 1983, as is evident from the trend line in Figure 6.5. Between 1983 and 2007, annual losses averaged about $0.4 billion (2018 dollars); in contrast, over the most recent decade, losses have averaged about $1.9 billion per year (Insurance Bureau of Canada, 2018). The largest insured loss in a single year on record was $5.3 billion (2018 dollars) in 2016, with the wildfire in Fort McMurray and the surrounding area resulting in insurance payouts totalling $3.9 billion (Insurance Bureau of Canada, 2019).

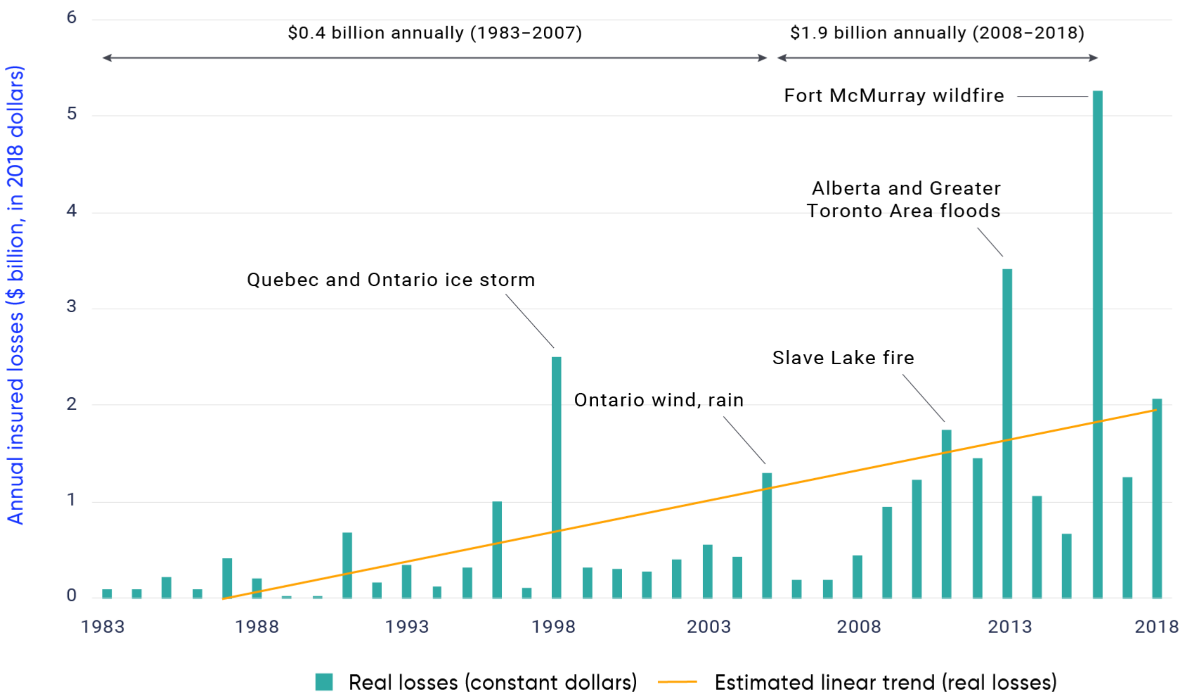


Figure 6.5: The figure shows annual insured losses plus adjustment expenses (in 2018 dollars) from extreme weather events in Canada over the period 1983–2018. The height of the bars shows the total losses plus expenses from all extreme weather-related events in each year. The solid orange line shows the estimated upward trend in insured losses plus adjustment expenses. Data source: Insurance Bureau of Canada, 2018.

Like insured losses, the number of extreme weather events has been increasing over time—the five-year moving average grew by about 7% annually between 1983 and 2018. In terms of the distribution of extreme weather events in Canada, Alberta was affected the most, with 55 events impacting the province over the period 1983–2018, followed closely by Ontario, with 52 events. The Maritime provinces experienced the fewest events. Alberta is the epicentre of extreme weather events when it comes to losses—six of the ten largest insured loss events in Canada since 1983 occurred in this province (*see* Table 6.1).

Table 6.1: Top 10 most costly weather-related disasters in Canada, in terms of insured losses (1983–2018)

RANK	DATE OF EVENT	AFFECTED AREA, PROVINCE	WEATHER-RELATED EVENT(S)	INSURED LOSS ($ MILLION)*
1	May 3–19, 2016	Fort McMurray, AB	Fire	3,899.1
2	January 1998	Southern Quebec	Ice storm	2,022.3
3	June 19–24, 2013	Southern Alberta	Flooding, water	1,737.4
4	July 8, 2013	Greater Toronto Area, ON	Flooding, lightning, water	1,004.6
5	August 19, 2005	Southern Ontario	Hail, tornadoes, wind	779.7
6	May 4, 2018	Hamilton, ON; Greater Toronto Area, ON; and Quebec	Windstorm, water	680.0
7	May 15–16, 2011	Slave Lake, AB	Fire, windstorm	587.6
8	August 7, 2014	Central Alberta	Windstorm, hail, lightning, water	582.3
9	August 12, 2012	Calgary, AB	Hail, lightning, water	571.8
10	July 12, 2010	Calgary, AB	Hail, flooding, windstorm, lightning	557.7

* All figures are in 2018 dollars.

Data source: Insurance Bureau of Canada, 2019.

As with payments from private insurers, the annual cost of the federal DFAA program has been rising since the 1970s (Office of the Auditor General Canada, 2016; Parliamentary Budget Officer, 2016). In the event of a disaster—and if the response and recovery costs exceed certain thresholds deemed acceptable for a province or territory to bear on its own—the Government of Canada provides financial assistance on a sliding scale through the DFAA program. Payments are made directly to provinces, which then distribute funds to individuals, businesses, non-profit organizations and local governments. Between 1970 and 1994, annual average DFAA payouts for hurricanes, convective storms, floods and winter storms averaged $56 million (2018 dollars) (Parliamentary Budget Officer, 2016). In contrast, annual average payouts averaged $303 and $427 million (2018 dollars) over the periods of 1995–2004 and 2005–2014, respectively (Parliamentary Budget Officer, 2016).

Long-term trends in losses have been interpreted as indicative of a contemporary adaptation deficit (Burton, 2009) and of increasing future climate-related risks (Hallegatte, 2014; Schipper and Pelling, 2006). There are many reasons for the observed adaptation deficit, including a range of market, behavioural and policy failures (*see* Section 6.8.1). The deficit has been increasing and is anticipated to widen with climate change (Burton, 2009), strengthening the case for early adaptation efforts.

6.4.4 What is influencing growing losses?

The observed increase in losses from weather-related disasters has led to questions about whether climate change is contributing to the trend (Bouwer, 2011). The IPCC, for example, suggested that the upward trend in historic losses provided indirect evidence of a potential climate change signal. However, some scholars argued that to make reliable comparisons between the losses of past and more recent weather-related natural disasters, it is necessary to control for changes in various socioeconomic factors that influence the magnitude of losses; otherwise, one is comparing apples to oranges (e.g, Pielke, 2007). The process of making adjustments for relevant socioeconomic and non-climate related factors is known as "loss normalization" (Swiss Re Institute, 2020; Pielke et al., 2003). Normalization helps to address the following question: "What would the magnitude of losses be if present-day assets and values were exposed to a historic event?" Analyses of normalized losses help to clarify the extent to which socioeconomic factors contribute to observed rising damages over time and, by inference, the role of other factors in shaping loss trends. One likely factor contributing to the trend of rising losses is improved and more comprehensive data collection over time; similarly, lower observed losses in the early 1980s may partly be explained by a lack of available data.

Studies that analyze time series of normalized economic and insured losses from weather-related disasters—whether they occur at a global or regional level—generate mixed results. Some studies find no significant upward trends, despite substantial increases in nominal losses (e.g., Bouwer, 2011; Neumayer and Barthel, 2011). Other studies find statistically significant long-term trends in losses (e.g., Gall et al., 2011; Schmidt et al., 2009). A recent study of normalized natural disaster losses globally uncovered strong evidence of a rightward skewing of the loss distribution and a corresponding increasing trend in the most extreme damages, but weaker evidence for an increasing trend in mean losses (Coronesea et al., 2019).

Figure 6.6 presents normalized insured losses for the same extreme weather events in Canada as shown in Figure 6.5. Losses are normalized using a conventional approach (e.g., Miller et al., 2008; Pielke et al., 2008; Pielke et al., 2003): the original nominal values, not adjusted for inflation, are modified by three multipliers to account for changes in producer prices, population and wealth, which are measured in terms of GDP per capita over time. A significant, though slightly weaker, positive trend is still observed in normalized losses from weather-related disasters in Canada. This upward trend is also evident when considering the five-year moving average of normalized losses, which produced an annual growth rate of 3.5% between 1983 and 2018; this rate was still increasing, but at a much slower rate than that of nominal losses (10.6%) and real losses (8.2%), adjusted for inflation, over the same period. Since 1983, the increasing trend in insured losses associated with extreme weather disasters in Canada has primarily been due to an accumulation of value (e.g., people, assets, wealth) year-on-year. But rising losses cannot entirely be explained by growing exposures, asset values and general price inflation—climate change may be playing a role. While a rise in normalized losses is not “proof” of climate change, it is certainly consistent with the anticipated intensification of some weather extremes with rising temperatures (Swiss Re Institute, 2020; Coronesea et al., 2019; IPCC, 2013).

Research on event attribution in Canada—which assesses how the likelihood of extreme weather events is altered by GHG emissions from human activity—found that climate change increased the likelihood of the 2016 Fort McMurray wildfire and the extreme rainfall that contributed to the 2013 flooding in southern Alberta (Zhang et al., 2019), two of the most costly weather disasters on record in Canada (*see* Prairie Provinces chapter).

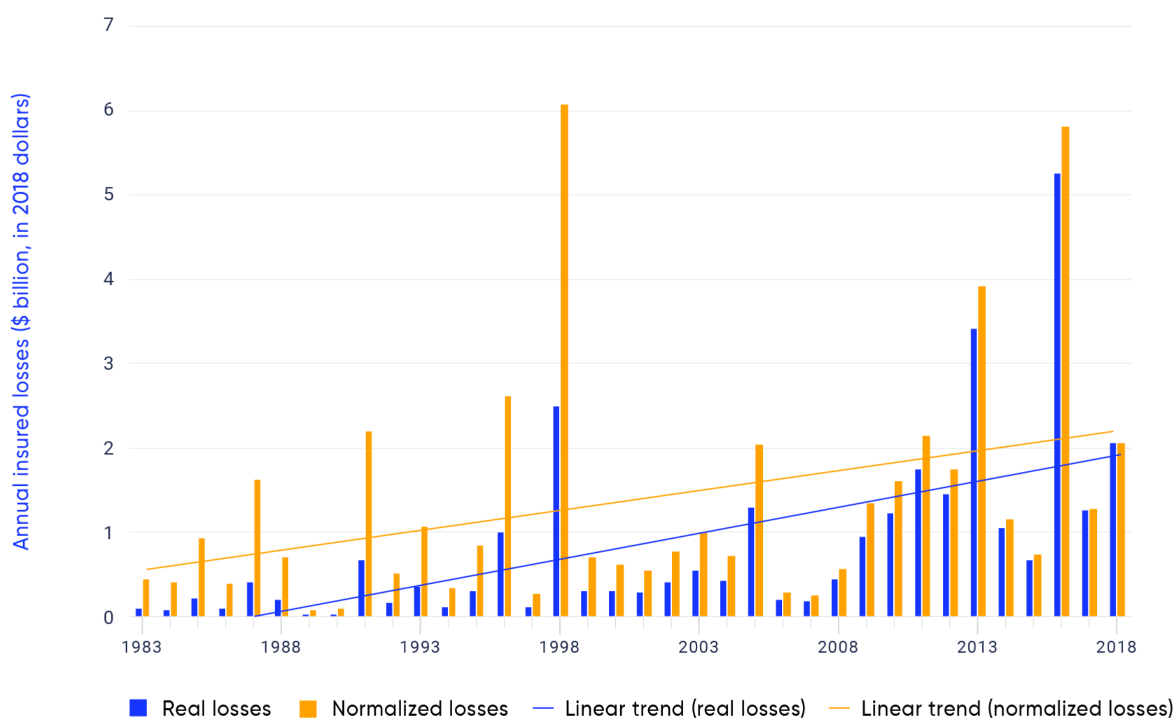


Figure 6.6: Normalized annual insured losses plus adjustment expenses (in 2018 dollars) from extreme weather events in Canada over the period 1983–2018. Losses are normalized following the approach used in Pielke et al., 2008, Miller et al., 2008, and Pielke et al., 2003, which adjusts for inflation and changes in population and wealth over time. The height of the bars shows the total normalized losses (orange) and real losses (blue), plus expenses from all extreme weather-related events in each year. The solid lines show the estimated upward trend in normalized losses (orange) and real losses (blue), plus adjustment expenses. Data source: Insurance Bureau of Canada, 2019.

6.5 Future climate change costs for Canada will be high

While climate change will present some benefits for Canada, the associated economic impacts are overwhelmingly negative. Much of the available evidence covers only a subset of the full extent of potential economic impacts from climate change for Canada. Projected costs are likely very conservative.

In the absence of new adaptation actions, the available evidence suggests that climate change will adversely impact the rate of economic growth in Canada and will result in negative economic consequences for forestry, coastal regions, the Great Lakes region (associated with low water levels), public health, and ski resorts in Quebec and B.C. Under high-emissions scenarios, the economic costs to these sectors could range from 100s of millions to 10s of billions of dollars annually by mid-century, and could amount to higher still by the end of the century. Most studies project economic benefits to the agriculture sector from climate change—with the largest gains in the Prairie provinces—while some large-scale global studies project minor losses for Canada's agriculture sector. The limited evidence available for cities suggests that climate change will have potentially significant negative economic impacts. Approaches for investigating the economic consequences of climate change have advanced considerably over the last decade. However, improving consistency across studies related to scope, assumptions and foundational data, and further refining methods are necessary to form more robust conclusions about the importance of economic impacts for one sector or region relative to another. There are also important knowledge gaps to fill. Information on the economic impacts of climate change is limited to a few sectors, regions and municipalities, and is lacking for Indigenous peoples.

6.5.1 Introduction

A key piece of economic information supporting climate-related decisions is the future cost of inaction—the economic consequences that result from allowing climate change to continue unabated and without further planned adaptation (Ackerman and Stanton, 2011; European Environment Agency, 2007). While the magnitude of the projected cost of inaction is uncertain, judiciously caveated estimates can be used in tandem with information on the current costs of climate and weather extremes (*see* Section 6.4) to persuade decision makers of the urgent need to allocate resources for adaptation, and to prioritize the allocation of such resources to address key climate risks. Projected costs also provide a baseline for weighing the cost of adaptation projects, programs and policies. To supplement the observed cost information for historic extreme weather events presented in Section 6.4, this section reviews available evidence relating to the projected future costs of climate change for Canada: looking at aggregate, multi-sector and national-level cost assessments; cost assessments for single climate-sensitive sectors at the national, regional and provincial level; and cost assessments for specific municipalities.

6.5.2 Multi-sector national cost assessments

Aggregate estimates of the economic consequences of climate change strictly for Canada and across multiple sectors are scarce. The frequently cited study by the NRTEE (2011) remains the benchmark multi-sector national assessment of the economic costs of climate change for Canada. Using the integrated assessment model, PAGE09 (Hope, 2011), the future economic cost of climate change for Canada was estimated for two climate and two socioeconomic scenarios, producing four plausible futures: 1) "low climate change–slow growth", 2) "low climate change–rapid growth", 3) "high climate change–slow growth" and 4) "high climate change–rapid growth".[2] Projected annual costs for Canada in 2050—assuming no new adaptations—range from $30 billion (2019 dollars) under the “low climate change–slow growth” scenario to $62 billion under the “high climate change–rapid growth” scenario. Under the “high climate change–rapid growth” scenario, more people, assets and wealth are exposed to a larger temperature change than under the “low climate change–slow growth” scenario, resulting in larger projected costs. The PAGE09 model explicitly captures uncertainty in its parameters, which generates a frequency distribution of estimated annual costs. The distributions of possible costs across all scenarios suggest a small chance that costs could be much higher—there is a 5% chance that the annual cost of climate change in 2050 could exceed $131 billion under the “high climate change–rapid growth” scenario. By 2075, under the same four plausible scenario combinations, annual costs are projected to range from $74 to $319 billion, with a 5% chance that they could exceed $1,185 billion annually under the “high climate change–rapid growth” scenario. These projections reflect the undiscounted expected costs to traditional economic sectors (e.g., construction, manufacturing, retail trade, educational services, etc.) and non-economic sectors (e.g., impacts to health and ecosystems) from warming, the expected costs of sea-level rise and the expected costs of “fat-tail” catastrophic events[3] (e.g., from rapid melting of the Greenland and West Antarctic ice sheets) (NRTEE, 2011).

The only other multi-sector national estimates of the aggregate impact of climate change on Canada come from large-scale global macroeconomic studies. Results for Canada from three of these studies are presented in Table 6.2. All three studies use similar approaches, which involve integrating information about biophysical impacts and economic valuation derived from independent damage assessments for specific sectors (like agriculture) into a multi-regional, multi-sector model of the global economy to estimate the impact of climate change on economic output (GDP). The studies include similar sector-specific impact categories (*see* Table 6.2) and draw damage information to inform the magnitude of projected impacts largely from the same set of primary studies (e.g., Lafakis et al., 2019; Kompass et al., 2018; Roson and Sartori, 2016; Kjellstrom et al., 2009; Bosello et al., 2006; Hamilton et al., 2005). Despite these similarities, the results are not strictly comparable due to, among other things, different time horizons and modelled temperature changes, and differences in how the independently estimated climate impacts are integrated into each macroeconomic model.

2 The low climate change scenario (IPCC SRES B1) assumes an annual average temperature change for Canada of +3.4°C by 2050, with a +28 cm rise in sea level. The assumed changes in temperature and sea level under the high-climate-change scenario (IPCC SRES A2) by 2050 are +3.6°C and +29 cm, respectively (NRTEE, 2011). Annual average growth in GDP under the slow-growth scenario and the rapid-growth scenario is assumed to be 1.3% and 3.0%, respectively (NRTEE, 2011).

3 A “fat-tail” catastrophic event is one where the costs of climate catastrophes are more probable, characterized by a probability distribution that does not have a typical bell shape, but rather has a long, fat tail that extends out to the right.

Table 6.2: Summary of national economic consequences for Canada from a selection of large-scale global macroeconomic studies

STUDY	PROJECTED IMPACT ON GDP	CLIMATE CHANGE SCENARIO	CATEGORIES OF CLIMATE CHANGE IMPACT INCLUDED IN THE ASSESSMENTS[1]
Organisation for Economic Co-operation and Development (2015)	**+0.89%** change in real GDP per year in **2060**, relative to projected GDP without climate change impacts	Projected regional change in mean annual temperature in 2060 under RCP8.5 relative to pre-industrial levels (1850–1900)	• **Agriculture and fisheries:** changes in crop yields and changes in fishery catches • **Coastal zones:** loss of land and capital from sea-level rise • **Extreme events:** damages from hurricanes • **Public health:** changes in labour productivity and healthcare expenditures due to vector-borne diseases, heat- and cold-related diseases, diarrhea • **Occupational health:** changes in labour productivity due to heat stress • **Residential energy demand:** changes in space heating and cooling costs • **Tourism:** changes in net tourism flows and associated expenditures

STUDY	PROJECTED IMPACT ON GDP	CLIMATE CHANGE SCENARIO	CATEGORIES OF CLIMATE CHANGE IMPACT INCLUDED IN THE ASSESSMENTS[1]
Kompass et al. (2018)	**-0.10%** (+1°C) to **-0.32%** (+4°C) change in real GDP per year in **2100**, relative to projected GDP without climate change impacts	+1°C to +4°C change in global mean annual temperature by 2100 relative to pre-industrial levels (1850–1900)	• **Agriculture:** changes in crop yields • **Coastal zones:** loss of land from sea-level rise • **Public health:** changes in labour productivity and healthcare expenditures due vector-borne diseases, heat- and cold-related diseases, diarrhea • **Occupational health:** changes in labour productivity due to heat stress
Lafakis et al. (2019)	**+0.31%** change in real GDP in **2048** (fourth quarter), relative to forecast GDP without climate change impacts	Projected global change in mean annual temperature in 2048 under RCP8.5 relative to 1986–2005	• **Agriculture:** changes in crop yields • **Coastal zones:** loss of land • **Public health:** changes in labour productivity and healthcare expenditures due vector-borne diseases, heat- and cold-related diseases, diarrhea • **Occupational health:** changes in labour productivity due to heat stress • **Residential energy demand:** changes in space heating and cooling costs • **Tourism:** changes in net tourism flows and associated expenditures

[1] Biophysical and economic impacts are derived from independent studies for each climate change impact category, and this information is used to develop “shocks” to the global macroeconomic models to simulate impacts on GDP. For example, Lafakis et al., 2019, used projected changes in oil prices to shock the Moody’s Analytical Macroeconomic Model for projected changes in residential energy demand related to climate change.

All three studies suggest that projected climate change impacts on annual real Canadian GDP will be less than (plus or minus) 1%. Though small in percentage terms from a national perspective, this still equates to very large dollar amounts, which will be significant for affected Canadian sectors and regions. Both the Moody's Analytics study and the OECD study project small net gains for the Canadian economy. In each case, the dominant driver behind the result is projected increases in tourism flows, with fewer domestic departures and more international arrivals expected as Canada warms. These gains more than offset output losses attributable to the other climate impacts that were analyzed. However, the projected increases in tourism flows for Canada should be viewed with caution, due to the simplified and aggregate nature of the underlying impact model, in which tourist flows only depend on mean annual temperature, per capita incomes, an attractiveness index, and the distance between the capitals of origin and destination countries (Hamilton et al., 2005). Other key determinants of future tourism flows are ignored, including the influence of changing precipitation patterns, supply-side constraints on the availability of tourist infrastructure, and feedback effects on international arrivals due to reduced incomes in origin countries related to climate change impacts on other sectors of the global economy. Kompass et al. (2018) deliberately excluded climate change damage functions for tourism from their analysis because of these concerns, and they projected small net losses for the Canadian economy related to climate change.

Estimates of the aggregate impact of climate change on the Canadian economy are available from another global macroeconomic study. Kahn et al. (2019) used a "top-down" empirical approach—which estimates a relationship between a climate variable (e.g., temperature) and an aggregate measure of economic output for the whole economy (e.g., national GDP)—to investigate the impact of climate change on long-term economic growth across 174 countries, including Canada. To put the results of this study into perspective, the PAGE09 integrated assessment model used by the NRTEE measures climate change impacts on GDP levels, not the GDP growth rate (i.e., it measures short-term growth effects). However, climate change can cause lasting damage to capital stocks and productivity in most sectors of the economy, and is likely to impact long-term growth rates (Revesz et al., 2014; Stern, 2013). In this case, output and consumption at some future date will not depend solely on the temperature at that date, but is more likely to be affected by the entire path of temperature, output and consumption up to that date. Studies that have investigated the impact of climate change on GDP growth rates have found substantially larger losses than studies that measured impacts on the annual level of GDP (Diaz and Moore, 2017a, b). The assessments summarized in Appendix 6.1 incorporated a mix of both effects—some of the sector-specific impacts that were analyzed affected GDP growth rates (e.g., damage from sea-level rise to capital stocks), while others affected output levels (e.g., changes to crop yields).

Kahn et al. (2019) used a model linking mean annual temperature deviations from historic norms over the period 1960–2014 to changes in labour productivity (*see* Case Story 6.2), and in turn to real GDP per capita. The model was used to investigate the cumulative effect of changes in labour productivity resulting from persistent increases in mean annual temperature under RCP8.5. In contrast to the projections presented in Appendix 6.1, Kahn et al. (2019) found that climate change would substantially reduce real GDP per capita in Canada in 2050 and 2100 by 4.4% and 13.1%, respectively.

The global macroeconomic studies discussed above have several limitations, meaning that the projected impacts of climate change for Canada are likely overwhelmingly negative and much higher than shown. For a start, many important impacts were omitted, including impacts on livestock and aquaculture, changes to forestry yields, impacts associated with the spread of invasive species and pests, impacts of water stress on electricity production and the availability of potable water for end users, impacts on human security (e.g., conflict and migration) and impacts on the provision of ecosystem services. Furthermore, macroeconomic studies cannot capture non-market impacts, such as welfare losses from impacts to cultural ecosystem services, premature mortality, or pain and suffering from illness or injury. The economic consequences of extreme weather events were also not covered, with the exception of hurricanes in the OECD study. The costs of these disasters can be considerable (*see* Sections 6.4, 6.5.2 and 6.5.3). Finally, large scale disruptive or "fat-tail" catastrophic events were not captured.

Case Story 6.2: The impact of climate change on labour and output

An emerging field of research on the macroeconomic consequences of climate change is the examination of the impact of temperature and heat stress on the productivity of workers across the economy (e.g., Newell et al., 2018; Heal and Park, 2016; Kjellstrom et al., 2015; Dell et al., 2014). There is an observable relationship between workplace temperatures and performance—beyond a certain temperature, the hourly productivity of workers or the time allocated to work declines (Zivin and Neidell, 2014; Dunne et al., 2013; Kjellstrom et al., 2013; 2009). For example, Vanos et al. (2019) found that labourers at an outdoor industrial site in Ontario lost, on average, 22 hours each summer (equivalent to about 1% of annual work hours) as a result of taking breaks or stopping work due to heat stress.

The risk of overheating increases with the level of physical exertion required to perform a given task, the duration of the task, the experience of the worker in performing the task and the ambient temperature of the work environment (Employment and Social Development Canada, 2018). Heat generated by the body needs to be transferred to the external environment to avoid increases in the body's temperature. If the body is unable to dissipate the heat, then it begins to experience dizziness, muscle cramps and fever. In extreme circumstances, exposure to hot temperatures can cause acute cardiovascular, respiratory and cerebrovascular distress, which can be life-threatening (Employment and Social Development Canada, 2018).

At lower temperatures in the workplace, before these more serious health effects occur, workers can experience diminished "work ability" (Kjellstrom et al., 2015), where temperature stress may affect workers in two ways (Heal and Park, 2016): 1) direct physical or psychological discomfort and 2) reduced task productivity, altering the increment of effort exerted within any given hour or the marginal return of that effort. These two direct effects may adversely affect labour supply and/or productivity, resulting in a loss of economic output (ILO, 2019; Dell et al., 2012). A growing body of literature finds that these losses can be substantial under different climate futures, especially for high-risk sectors with a largely outdoor workforce (e.g., agriculture, forestry, construction, mining, transportation, utilities) (Zivin and Neidell, 2014). For example, the US Environmental Protection Agency (2017) found that about 1.9 billion labour hours in high-risk sectors will be lost annually in the United States by 2090 under RCP8.5 due to workplace exposure to temperature extremes (i.e., mean daily maximum temperatures above 80 °F) (*see* also Chavaillaz et al., 2019; Behrer and Park, 2017; US Environmental Protection Agency, 2015; Rhodium Group, 2014; Kovats et al., 2011). This equates to about $160 billion (2015 US dollars) in foregone wages—gross wages are used as a proxy measure for the value of lost economic output (US Environmental Protection Agency, 2015)—per year by 2090, which represents just under one-third of the total estimated annual damages under RCP8.5 across all impact categories analyzed. Projected impacts on labour productivity were the most economically significant impact category (US Environmental Protection Agency, 2017).

Estimates of the impact of climate change on occupational heat stress and associated labour decisions, labour productivity and economic output for Canada are only available from global studies, and only at the national level (e.g., Chavaillaz et al., 2019; Kahn et al., 2019). Kahn et al. (2019) found that the cumulative effect of changes in labour productivity due to persistent increases in mean annual temperature under RCP8.5, relative to historic norms over the period 1960–2014, substantially reduced real GDP per capita in Canada in 2050 and 2100 by, respectively, 4.4% and 13.1%. One would expect these national-level losses to be unevenly distributed across Canada. The magnitude of losses in a region will depend on the projected shift in the historic distribution of daily temperatures with climate change and the structure of economy, in terms of the relative contributions of high-risk (largely outdoor workforce) and low-risk (largely indoor workforce) sectors to aggregate output.

The available evidence makes a strong case for including impacts on occupational heat stress in future macroeconomic analyses of the economic consequences of climate change for Canada. It is important that such assessments account for heterogeneity between regions in terms of the sectoral make-up of the economy.

6.5.3 Sector and regional cost assessments

While only a few studies provide aggregate cost estimates across multiple sectors for Canada,many more studies have investigated the economic consequences of climate change for individual climate-sensitive sectors (e.g., forestry, agriculture, coastal areas). Appendix 6.1 provides a summary of these studies and results, organized by climate-sensitive sector.

It is nearly impossible to compare the relative magnitude and significance of estimated economic consequences between climate-sensitive sectors, or even within a sector, due to differences in assumptions and methodologies across studies. In addition to differences in geographical scope, key differences between studies that influence the results relate to:

- The choice of emissions scenario(s) driving the biophysical impacts and, relatedly, the future time period(s) and climate norms used to measure changes in relevant climate variables. Looking at coastal areas, for example, some studies use the old IPCC Special Report on Emissions Scenarios (SRES), whereas others use the Representative Concentration Pathways (RCPs). This affects the time horizon over which streams of losses or gains are aggregated (e.g., the studies in Appendix 6.1 assessing the same coastal area sites use three different time periods: 2009–2054, 2015–2064 and 2011–2100).

- Assumptions about future socioeconomic developments, which will influence both the quantity and monetary valuation of buildings, infrastructure, crops, etc. that are affected under the assumed baseline and against which the impacts of projected climate change are assessed. Some of the studies examined the impact of future climate change on the sector today (based on current or historical information), while others—such as the NRTEE (2011) forestry and coastal area studies—investigated the impact of future climate change on future projections for the sector.
- Whether one or more biophysical impacts are considered. For example, some studies that focused on coastal areas included erosion and flooding from sea-level rise and storm surge, while others only considered impacts from flooding.
- The types of economic consequences resulting from the biophysical impacts included in the analysis. Most studies considered only direct impacts (e.g., damage-related costs, changes in agricultural land values, foregone ski revenues, increases in ski resort operating costs or fire suppression costs), while some studies also assessed indirect and macroeconomic impacts. The more recent studies measured economic consequences in terms of changes in projected GDP or welfare, which were estimated using CGE models. Furthermore, some studies that measured only direct impacts considered both market and non-market impacts (e.g., coastal area studies for Quebec), while others included only the former.
- The choice of economic modelling tool, specifically with respect to agriculture. Most agricultural studies estimate using a Ricardian model (an approach that estimates an empirical relationship between land values and climate variables) to measure the economic consequences of climate change on farmland values, while some use CGE models. As noted above, CGE models measure direct and indirect impacts, and account for market-driven behavioural (price) responses throughout the economy; Ricardian models capture only direct impacts and typically assume that prices are fixed. Results from both modelling approaches applied to agriculture are not comparable.
- Whether the economic consequences are measured in current (nominal) dollars or constant (real) dollars, and which base year is selected in the latter case (e.g., coastal area studies measured costs in 2000, 2008 and 2012 constant dollars). This is less of an issue, though, since it is possible to express all results in the prices of a common base year.
- The choice of discount rate, where results are reported as the present value of cumulative losses or gains over a defined time horizon (e.g., some studies use a real annual discount rate of 3%, whereas others use 4%). A higher discount rate will produce lower present-value costs or benefits, and a lower discount rate will produce the opposite. For reference, the value of a $1 cost (in 2020) incurred in the 2080s is $0.15 and $0.08 at a discount rate of 3% and 4%, respectively. Some studies also present undiscounted costs or benefits. Discounting and discount rates are discussed in Section 6.6.3.2.

While the above factors make it difficult to arrive at firm conclusions about the magnitude of economic impacts, it is possible to draw conclusions about the direction of projected impacts for all sectors studied, except for agriculture. The available evidence (based on the studies listed in Appendix 6.1) suggests that climate change will have predominantly negative economic consequences for forestry, coastal areas, human health in Quebec, low water levels in the Great Lakes and St. Lawrence River region, ski resorts in British Columbia and Quebec, and ice-based access roads in the Northwest Territories. Below are key observations across this series of studies, by climate-sensitive sector.

6.5.3.1 Forestry

Climate change impacts on timber supply (related to factors such as forest productivity, fires, pests and disease) are projected to reduce forest sector output, GDP and welfare. Nationally, present-value cumulative GDP losses over 70 years through 2080 could be as high as $459 billion (2008 dollars), without adaptation measures (Ochuodho et al., 2012). Losses are not evenly distributed across Canada—British Columbia, Saskatchewan, Manitoba and the Territories are the worst affected areas in terms of projected GDP losses (Ochuodho et al., 2012; NRTEE, 2011). In contrast, Quebec and Ontario could experience slight improvements in GDP under the most optimistic scenario of climate change impacts on timber supply, and modest losses under the most pessimistic scenario (Ochuodho et al., 2012). Climate change is also projected to increase historical fire management costs nationally by 60–120% per year by the 2080s, with Alberta and Saskatchewan seeing much larger increases in costs than the national average (Hope et al., 2015).

6.5.3.2 Coastal regions

Climate change is projected to impose costs on Canada's coastal regions. By 2050, annual damages from coastal flooding attributable to climate change could range from $1 to $8 billion (in 2008 dollars), depending on the growth and emissions scenario (NRTEE, 2011). In present value terms, cumulative losses over the period of 2011–2100 could be as high as $380 billion (in 2008 dollars) (NRTEE, 2011). As in the forestry sector, losses are distributed unevenly across Canada—British Columbia is estimated to incur the largest losses, accounting for upwards of 80–90% of the total losses nationally (Withey et al., 2016; NRTEE, 2011). Detailed regional studies of specific stretches of coast in Quebec and Atlantic Canada also find significant variation in projected losses, suggesting that the economic costs of climate-related coastal flooding are very site-specific (Boyer-Villemaire et al., 2016; Circé et al., 2016b; Parnham et al., 2016).

6.5.3.3 Water levels

Low water levels in parts of the Great Lakes–St. Lawrence River system due to future climate change are anticipated to adversely affect a range of economic activities, recreational opportunities and other shoreline amenities. Present-value cumulative costs associated with these impacts are projected to amount to $12 billion over 50 years through 2065 (in 2012 dollars) (Dorling and Hanniman, 2016; Millerd, 2005). Approximately 90% of these costs result from three economic impacts: the replacement of lost hydroelectric output (50%), foregone earnings from ecological services and fishing (25%) and lost shipping capacity (15%) (Dorling and Hanniman, 2016; Millerd, 2005).

6.5.3.4 Human health

Changes to the incidence of climate-sensitive health outcomes under future climate conditions can increase healthcare expenditures and welfare losses. In Quebec, the present value of cumulative expenditures on health services attributable to the impact of climate change on vector-borne diseases, extreme heat events and aeroallergens is estimated at just under $1 billion over 50 years through 2065 (in 2012 dollars) (Larrivée et al., 2015). The present value of cumulative welfare losses associated with increased mortality—measured using the Value of Statistical Life—is approximately $35 billion (in 2012 dollars) over the same period (Larrivée et al., 2015). This finding is consistent with other economic studies of the impact of climate change on human health; welfare losses can substantially exceed healthcare resource costs (e.g., Paci, 2014; Kovats et al., 2011).

6.5.3.5 Ski resorts

Climate change is anticipated to adversely impact the economic viability of ski resorts. For instance, the net income of three resorts in Quebec is estimated to fall by just under 30% over a 20-year period through 2045, as a result of changes in the length of the ski season and in snow conditions (DaSilva et al., 2019). Evidence for Fernie and Whistler in British Columbia also shows that the impact of climate change on snow conditions can reduce the value of property in resorts (Butsic et al., 2011).

6.5.3.6 Agriculture

In contrast to other climate-sensitive sectors, most of the available literature summarized in Appendix 6.1 suggests that the economic consequences of climate change for agriculture in Canada could be positive and potentially significant—even by the 2080s—and especially for the Prairie provinces. For example, estimated increases in farmland values by the 2050s on the Prairies resulting from climate change are as high as +40% (Amiraslany, 2010). The exception is a small area of southeast Alberta, where farmland values are anticipated to decrease through the century. In dollar terms, projected increases in farmland values on the Prairies by the 2050s could amount to just under 25% of the value of agricultural GDP in 2011 (Amiraslany, 2010). These estimated benefits are derived from Ricardian models of agricultural land values and should thus be viewed as optimistic. It is assumed that the estimated relationships embedded in these statistical models are valid beyond the range of empirical evidence from which they were derived; however, this may not be the case, especially towards the end of the century. Furthermore, the estimated relationships capture historical autonomous adaptations by farmers. However, farmers may face new barriers to private action in the future (*see* Section 6.8.1), reducing the efficacy of autonomous adaptation. None of the agricultural studies in Appendix 6.1 account for the impacts of climate and extreme weather events on agricultural output and land values, nor do they account for the changes in pest damage or the timing of precipitation.

Studies using CGE models—which capture interprovincial and international trade flows—have produced more conservative and differing values. One study indicated that climate change impacts on agricultural crops would increase GDP in Canada through 2050 (Ochuodho and Lantz, 2015), while another study that considered impacts on livestock and processed foods, in addition to impacts on crops, estimated that GDP in Canada would decrease slightly by the 2080s (Zhai et al., 2009). The latter result was mainly due to large decreases in livestock output. Using a global multi-sector model, the Organisation for Economic Co-operation and Development (2015) likewise projected a decline in GDP from climate change impacts on agriculture in Canada by 2060.

One study (Ochuodho and Lantz, 2015) that generated regional results for Canada using a CGE model found the largest GDP gains primarily in the Prairie provinces, in terms of percentage increases in GDP. Interestingly, GDP increases due to climate change do not translate into proportional welfare changes for consumers and do not necessarily lead to increased welfare. Price changes, input substitution and trade dynamics may result in welfare losses for consumers, despite increases in GDP. For example, the present cumulative GDP value in Manitoba over 45 years is projected to increase by 1.3%, while welfare is projected to decline by 0.1% over the same period. For the same reasons, while increasing the wealth of farmers, the beneficial impacts of climate change estimated by the Ricardian models do not necessarily translate to improvements in consumer welfare.

6.5.4 Municipal cost assessments

Projections of the economic consequences of climate change have also been made for individual cities in Canada. Appendix 6.2 provides a summary of key city-specific studies, which vary markedly in scope, methods, emissions scenarios, socioeconomic assumptions, time horizons considered and measures of economic impact, making comparisons difficult. The small number of studies also makes it difficult to draw assured conclusions. Nevertheless, initial observations from the available evidence suggest that the net economic consequences of climate change for cities are projected to be negative.

It is also evident from the studies in Appendix 6.2 that the scope of the analysis—the number of climate hazards, biophysical impacts and exposures considered, and whether the economic impacts include both direct and indirect impacts, as well as market and non-market impacts—is an important determinant of the magnitude of projected costs. For example, non-market impacts accounted for 23–42% of total flooding costs in Fredericton due to climate change (Lantz et al., 2012). The omission of non-market impacts from these analyses would result in a significant underestimate of projected climate-related costs. The scope of the City of Edmonton analysis (*see* Case Story 6.3) was more comprehensive than the other city studies and included many more climate-related impacts (17 rapid-onset impacts alongside changes in heating and cooling degree days) on a broader inventory of exposed buildings, assets, infrastructure and services, as well as non-market economic impacts on human health and the natural environment. This more expansive scope also included direct and indirect impacts, explaining why the projected climate-related costs found by the study are relatively high; expected annual GDP costs are $1.6 billion in 2055 and $3.5 billion in 2085 (both in 2016 dollars), which is equivalent to 1.6% and 1.9%, respectively, of the city's projected GDP.

All studies employed bottom-up, process-based modelling approaches. The City of Edmonton and the Cities of Halifax and Mississauga studies also adopted good practices, determining incremental losses attributable to climate change with and without socioeconomic development relative to today. This allows for an analysis of how socioeconomic development in relation to climate change contributes to projected economic costs, as well as an analysis that isolates the fraction attributable solely to climate change. Consistent with observations from the multi-sector regional studies discussed in Section 6.5.3, growth in the "stock at risk" to climate change and rising valuations of that stock can be an equally important determinant of future economic costs as climate change itself (*see* Case Story 6.3).

Case Story 6.3: The City of Edmonton's assessment of the net costs of climate change

In 2016, the City of Edmonton began an investigative process to better understand how the local climate has changed historically and how it might change in the future. As part of the process, a multi-sector, stakeholder-led climate vulnerability and risk assessment (VRA) was conducted to measure potential risks and opportunities resulting from these changes. This included quantifying both the social costs and GDP costs of climate change for Edmonton to strengthen the business case for action. The scope of the VRA and economic analysis (Boyd, 2018) was extensive and included adopting a community-wide approach, as well as considering climate-related biophysical impacts to 17 "asset-service areas" (e.g., population health, critical infrastructure, roads, managed natural areas, urban forest, buildings, etc.). Impacts and costs attributable to 19 climate hazards were assessed, including a range of extreme events (e.g., extreme heat, freezing rain, high winds, heavy rainfall, etc.) and slow-onset changes (e.g., timing of the frost-free period, heating degree days, etc.). For each extreme event considered, impacts were quantified for a specific level of intensity (e.g., wind speeds ≥ 90 km per hour). The following impact chains were included in the analysis:

- Direct physical damage to, or loss of, public and private infrastructure, buildings and facilities (e.g., repair and replacement costs for structures, equipment, contents and inventories);
- Direct physical and mental, morbidity and mortality health outcomes (e.g., welfare losses);
- Direct physical damage to, or loss of, managed natural sites and urban trees (e.g., restoration and replacement costs);
- Service losses from damage to, or loss of, urban trees (e.g., foregone non-market ecological value);
- Service losses from impairment to aquatic and terrestrial ecosystems (e.g., foregone non-market ecological value);
- Road transportation service losses (e.g., total value per foregone passenger-kilometres travelled and per foregone freight vehicle kilometres travelled);
- Service losses from residential buildings (e.g., relocation costs); and
- Service losses from damaged public, commercial and industrial buildings (e.g., relocation costs, value of lost output).

The projected costs of climate change for Edmonton were estimated in four steps:

1. Biophysical impacts and costs were assessed for the exposure of Edmonton's 2018 inventory of all "assets/services" to average climate conditions over the 1981–2010 climate normal. This provides a baseline measure of costs in 2018.
2. To account for future socioeconomic development, each component in the 2018 inventory of assets/services was projected through to 2100, using a combination of existing growth studies for Edmonton and relationships estimated from historical data. Relevant market and non-market valuation data were likewise projected through to 2100. The projected future inventory and value of all "assets/services" was then re-exposed to average climate conditions over the 1981–2010 climate normal. The incremental annual costs attributable to socioeconomic development in the absence of further climate change (and assuming no additional planned adaptation) was estimated at about $3.1 billion by the 2050s and $8.5 billion by the 2080s (*see* Figure 6.7a). These cost projections reflect the undiscounted stream of costs (in 2016 constant dollars) attributable to climate-related impacts on Edmonton in an average year, centered within each time period (2041–2070 and 2071–2100).
3. The projected future inventory and value of all "assets/services" is exposed to projected climate conditions under RCP8.5 for the 2050s and 2080s (assuming no additional planned adaptation). For extreme events within scope, only changes to their annual probability of occurrence were modelled; the intensity of the event was held constant. The incremental annual costs attributable to climate change and socioeconomic development were estimated at about $7.8 billion by the 2050s and $19.1 billion by the 2080s.
4. The incremental or imposed cost of projected climate change on a future Edmonton was estimated by examining the difference between the results of step 3 and step 2. By the 2050s and 2080s, the imposed annual cost of climate change on a concurrent future Edmonton is projected to be about $4.7 billion and $10.3 billion, respectively.

Provincial input-output tables were used in combination with employment and output data for Edmonton to generate city-level GDP, labour income, employment and output multipliers. These multipliers were subsequently applied to projected output losses (i.e., the market-based components of the costs shown in Figure 6.7a) to estimate the total direct, indirect and induced annual GDP cost of climate change for Edmonton. The GDP cost for the City of Edmonton imposed by climate change is about $1.6 billion annually by the 2050s, rising to about $3.5 billion annually by the 2080s (*see* Figure 6.7b).

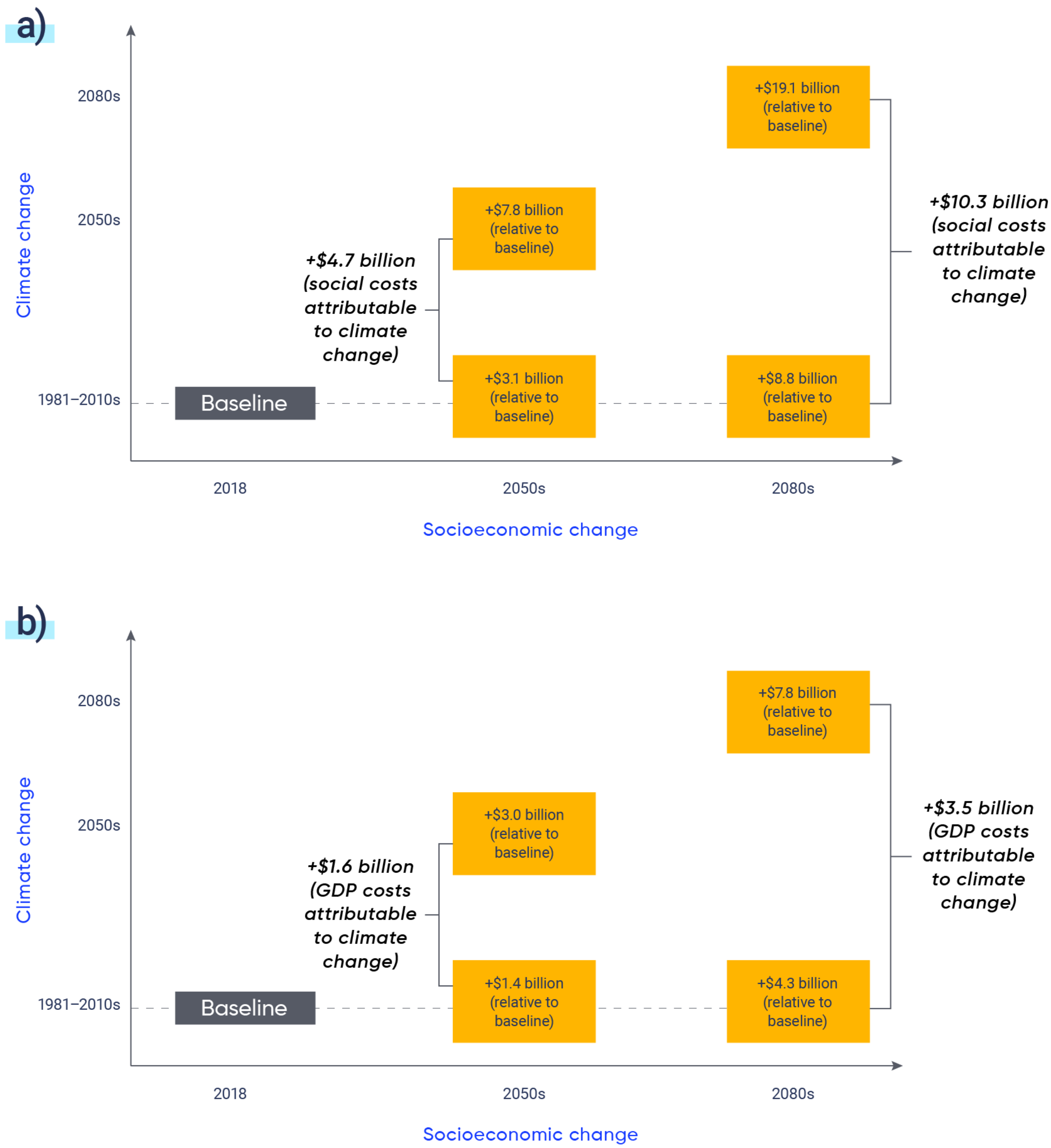


Figure 6.7: a) Projected annual social costs and b) Gross Domestic Product (GDP) costs for the City of Edmonton attributable to climate change by the 2050s and 2080s. Source: Adapted from Boyd, 2018.

The damage functions underlying the results shown in Figure 6.7 were used to present the rising economic consequences of projected climate change on Edmonton, as functions of increasing mean annual temperature above the 1981–2010 climate normal (*see* Figure 6.8).

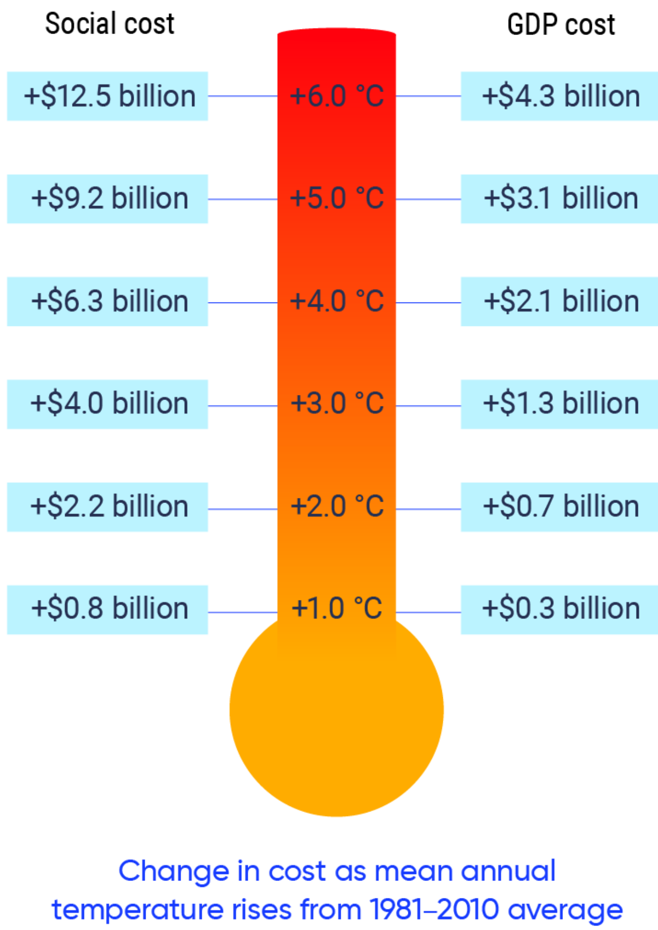


Figure 6.8: Projected annual social and Gross Domestic Product (GDP) costs for the City of Edmonton attributable to different levels of climate change above the 1981–2010 climate normal. Source: Adapted from Boyd, 2018.

6.6 Economic decision support tools help with assessing adaptation options

Economics offers a range of tools to help decision makers appraise adaptation actions, understand trade-offs and generate information on the costs and benefits of different options. The appropriate economic tool to use depends on the criteria for the adaptation decision, the nature of the climate change impacts and the level of uncertainty.

Although there is no one-size-fits-all approach, economics offers a range of tools that can support decision makers in appraising adaptation options—each tool has strengths and weaknesses depending on the context for the adaptation decision. Appraising adaptation actions requires weighing a diverse range of factors, as well as quantifiable financial costs and benefits. This includes non-monetary and non-market impacts, positive and negative co-impacts, barriers to implementation, equity and, importantly, uncertainty. There are methods to capture distributional impacts, intergenerational equity issues and non-market impacts within traditional economic decision-support tools like cost-benefit analysis (CBA). There are also a range of new approaches that work with traditional tools like CBA, but are better at supporting decision making under deep uncertainty, and incorporating the time-phasing of actions and multi-metric evaluations, such as adaptation pathways and robust decision making. When the chosen economic tools do not account for this diverse range of factors, decision making can be biased against vulnerable populations, disadvantaged groups, future generations, and "soft" actions with fewer quantifiable costs, benefits and non-market impacts.

6.6.1 Introduction

In addition to seeking evidence on the economic consequences of climate change, decision makers are increasingly requesting information on the costs, benefits and key trade-offs of actions to support their adaptation decisions. This section provides a review of economic analysis tools to support adaptation decision making and will provide context for the next section, which reviews the application of these tools in Canada. Prior to an examination of the economic decision support tools, common evaluation criteria are introduced to highlight the trade-offs that decision makers often consider in making adaptation decisions.

6.6.2 Decision criteria

Decision makers bring diverse objectives, interests, knowledge and values to climate change adaptation decisions. This results in a diverse range of decision criteria to consider as various courses of action are weighed. The literature contains many decision criteria and groupings of those criteria to support the appraisal of adaptation actions and their implementation (e.g., Rouillard et al., 2016b; Weiland and Tröltzsch, 2015; PROVIA, 2013; United Nations Environment Programme, 2011). These reviews conclude that the appraisal of adaptation actions should ideally capture trade-offs between all relevant outputs (benefits) and all relevant inputs (costs) that are needed to deliver those outputs. Two further important considerations relate to uncertainty surrounding the anticipated outputs and the ease with which an adaptation action can be successfully implemented, which will also affect costs. Based on these reviews, the main decision criteria typically used to assess the relative merit of investment in adaptation actions are described in Table 6.3.

Table 6.3: Description of main decision criteria commonly used to appraise adaptation actions

INPUTS		POTENTIAL GOAL OF THE DECISION MAKER
Costs	**Total lifecycle costs** The total costs of the adaptation action, including the following, where relevant: upfront investment costs (capital), annual recurring costs (operations and maintenance), renewal and reinvestment costs, decommissioning costs and transaction costs.	Minimize total lifecycle costs for a given target output.
	Negative co-impacts Negative side-effects of the adaptation action for other economic, social or environmental objectives of the decision maker. Examples include increasing GHG emissions, increasing risks to other groups or sectors that are not the target of the option, or limiting future adaptation options.	Keep aggregate negative co-impacts to a minimum.
Ease of Implementation	**Feasibility** The capacity of the decision maker to successfully implement the adaptation action, including accessing the necessary knowledge, technologies, human resources, budget etc. (all of which could act as barriers to action). Feasibility is also influenced by the presence of entry points or windows of opportunity to implement the option.	Prioritize the most feasible actions.

INPUTS		POTENTIAL GOAL OF THE DECISION MAKER
Ease of Implementation (continued)	**Acceptability** The degree of social, cultural, economic and political support for the adaptation action, both from those directly affected (i.e., groups that benefit and bear costs) and the general public.	Prioritize actions with the most support and the least opposition.
OUTPUTS		**POTENTIAL GOAL OF THE DECISION MAKER**
Benefits	**Effectiveness** The degree to which the adaptation action achieves the goal(s) of the decision maker (e.g., reduces anticipated adverse consequences of a specific climate-related threat, enables anticipated beneficial consequences of a climate-related opportunity to be realized, etc.).	Maximize effectiveness through project design.
	Relevance The significance of the climate-related threat or opportunity targeted by the adaptation action. Threats and opportunities with "extreme" consequences that are "almost certain" to occur would have high relevance.	Prioritize actions that target threats or opportunities of highest relevance.
	Co-benefits Positive side-effects of the adaptation action for other economic, social or environmental objectives of the decision maker. Examples include GHG emissions reduction, recreation opportunities, maintaining or enhancing ecosystem services, employment opportunities, encouraging innovation and decreasing risks to other groups or sectors that are not the target of the option.	Take account of aggregate positive co-impacts when selecting among candidate adaptation options.

	OUTPUTS	POTENTIAL GOAL OF THE DECISION MAKER
Benefits (continued)	**Equity** Equitable distribution of adaptation costs, benefits and residual impacts between population groups and generations. The action benefits the broadest possible range and number of people. Equity also encapsulates the degree to which options reduce existing inequalities (e.g., to disadvantaged groups or neighbourhoods).	Prioritize equitable actions that support disadvantaged and low-income groups, and that address existing inequalities.
Uncertainty	**Urgency** Refers to how soon the adaptation action needs to be implemented. Addressing priority threats or opportunities that occur under current climate conditions would be assigned greater urgency than actions that target threats or opportunities expected only under projected future climate conditions. Adaptations that target future threats and opportunities with the potential to affect near-term decisions with long lifetimes, such as current land-use planning and infrastructure choices, would also be treated with greater urgency.	Prioritize actions that address risks from current climate conditions or that mainstream adaptation considerations into near-term, long-lived decisions.
	Static robustness The degree to which an action is effective in terms of achieving the decision maker's objectives, over a range of plausible emissions scenarios and socioeconomic scenarios. This criterion is most relevant to near-term, long-lived decisions.	Prioritize actions that reduce vulnerability to the largest possible range of future climate and socioeconomic conditions.
	Dynamic robustness (flexibility) Adjustable actions that can be implemented incrementally and readily adapted if future climate and socioeconomic conditions change or turn out differently from what is expected today. This criterion is also most relevant to near-term decisions with long lifespans.	Prioritize actions that are readily adaptable to changing climate and socioeconomic conditions, with minimal transition costs.

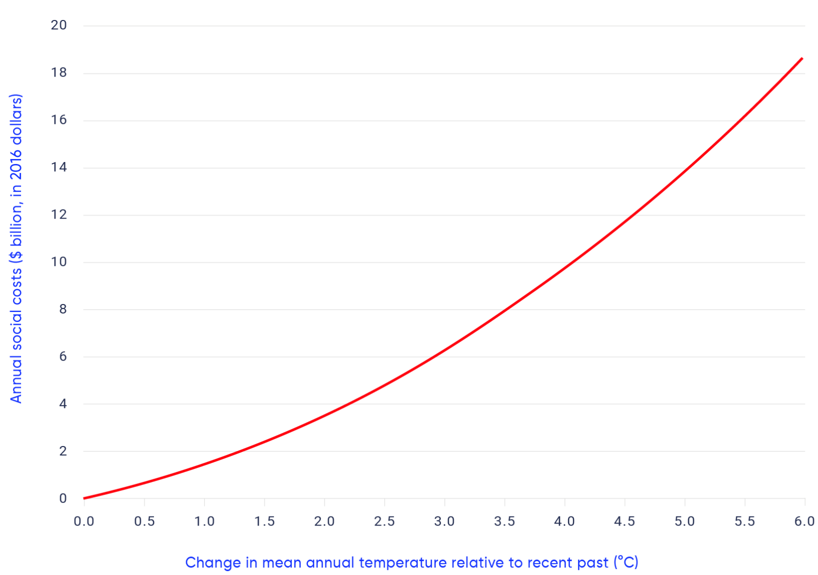
Source: Weiland and Tröltzsch, 2015; PROVIA, 2013

6.6.3 Conventional economic decision support tools

There are multiple methods for appraising adaptation actions. The standard analytical technique used for the economic appraisal of policies, programs and projects is cost-benefit analysis (CBA) (*see* Figure 6.9). CBA is a suitable method for economic appraisal when the adaptation goal is to minimize the economic costs of a climate-related threat or to maximize the economic benefits of a climate-related opportunity. In some decision contexts, however, the adaptation goal might be to achieve a given level of risk reduction or to cancel out all adverse climate-related impacts (i.e., to maintain baseline conditions) (Chambwera et al., 2014). In this context, the other main economic appraisal method, cost-effectiveness analysis (CEA), could be used to identify the action or portfolio of actions necessary to achieve this goal at the lowest cost or the greatest level of risk reduction for a fixed investment budget.

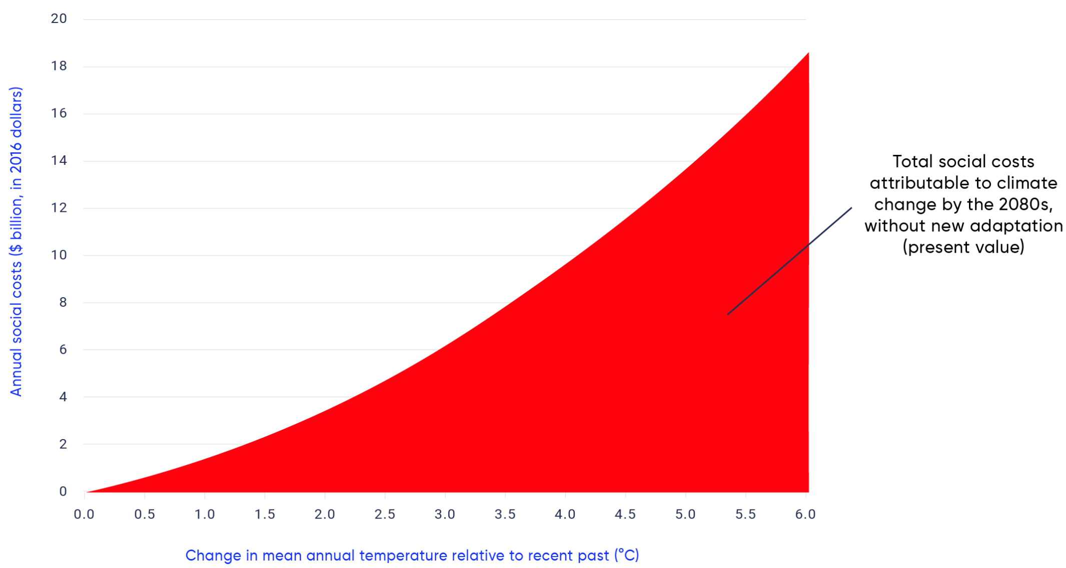
A third traditional method that can be used to appraise adaptation actions is multi-criteria decision analysis (MCDA). Though it is not technically an economic appraisal tool, it can accommodate monetized costs and benefits information in the decision calculus, alongside a range of other decision criteria. A decision maker may want to use MCDA when economic efficiency is not the sole decision criterion of interest or when important inputs to, or outcomes of, the adaptation action cannot be valued in monetary terms. Given the multiple criteria now being considered when making adaptation decisions, increasing emphasis is being placed on such "multi-metric" appraisal tools to provide support for decision makers (*see* Table 6.4; Chambwera et al., 2014).[4] Only CBA, however, has been applied in the available literature for Canada (*see* Section 6.7).

a)



4 Interested readers can access several guidelines that focus on the economic appraisal of adaptation actions—e.g., Asian Development Bank (2015); Meyer et al. (2015); Boyd et al. (2013); PROVIA (2013); USAID (2013); Economics of Climate Adaptation (2009) and Metroeconomica (2004). Other resources are available that provide specific guidance to help with selecting economic appraisal methods (e.g., Tröltzsch et al., 2016; Watkiss et al., 2015a; Swart and Singh, 2013; and Watkiss and Hunt, 2013).

b)


20
18
16
14
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8
6
4
2
0
Annual social costs ($ billion, in 2016 dollars)
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2.0
2.5
3.0
3.5
4.0
4.5
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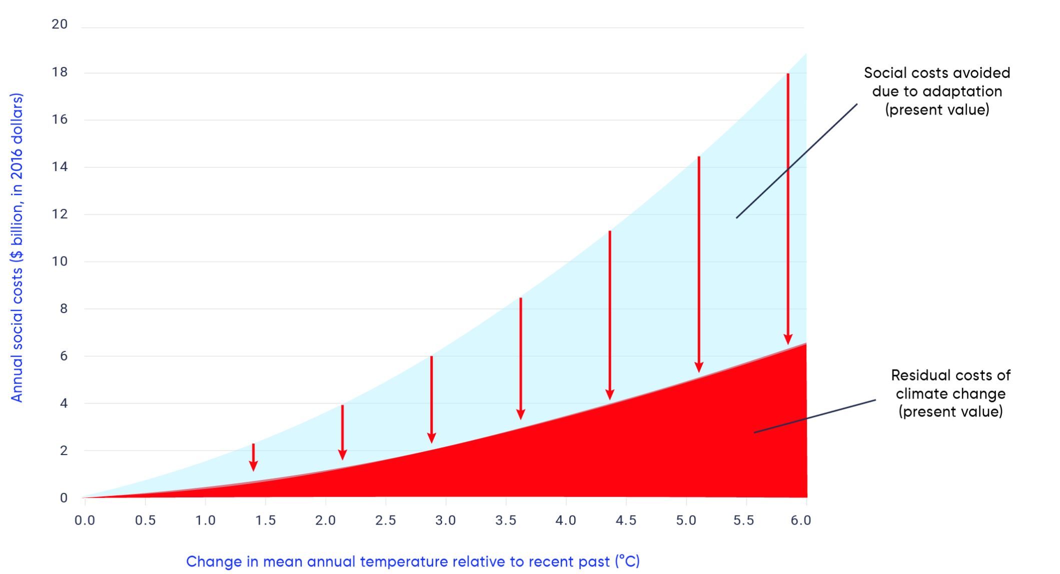
5.5
6.0
Change in mean annual temperature relative to recent past (°C)
Total social costs attributable to climate change by the 2080s, without new adaptation (present value)

c)


20
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Annual social costs ($ billion, in 2016 dollars)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Change in mean annual temperature relative to recent past (°C)
Social costs avoided due to adaptation (present value)
Residual costs of climate change (present value)

d)

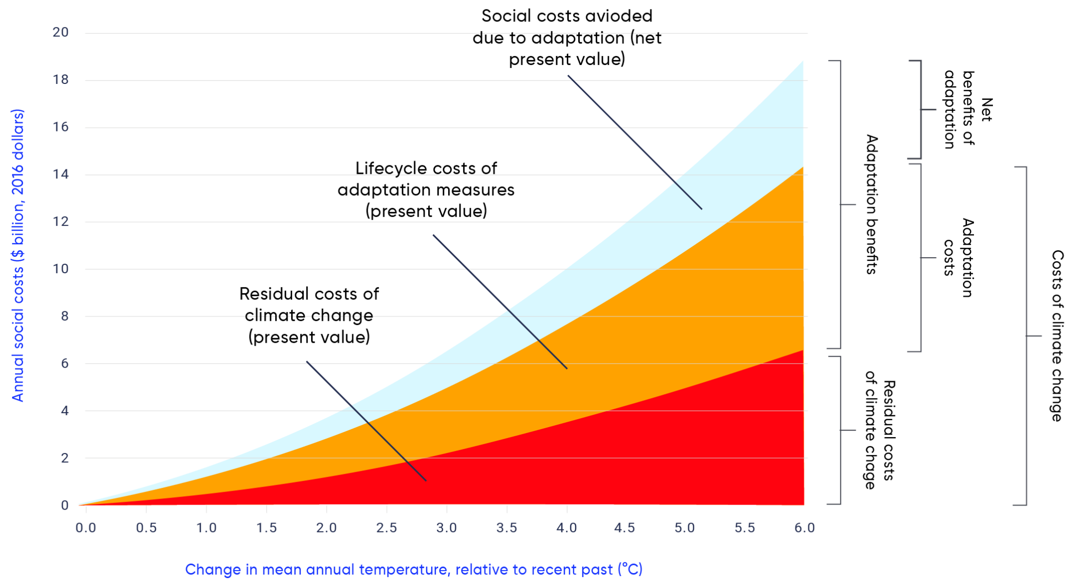


Figure 6.9: This stylized depiction of present-value benefits, costs and residual damage costs of adaptation (in 2016 dollars) assumes that the decision makers' objectives are as follows: to reduce negative impacts and minimize the total cost of climate change. a) Projected baseline scenario (estimated damage function with climate change), b) estimated present-value social costs of climate change under the baseline scenario with no new adaptation actions, c) estimated reduction in projected social costs with new adaptation actions (i.e., defines the present-value benefits of adaptation), and d) estimated net benefits of adaptation actions, once the lifecycle costs of actions are taken into account. Source: Adapted from Metroeconomica, 2004, and based on the social cost damage function for the City of Edmonton in Boyd, 2018.

Table 6.4: Commonly used economic appraisal methods for adaptation decision support

TOOL	SUMMARY	UNCERTAINTY	BENEFIT METRIC	COMPLEXITY
Cost-Benefit Analysis (CBA)	This method appraises options in terms of their monetary value, weighing the lifecycle costs of options against projected benefits (e.g., Boyer-Villemaire et al., 2016). The option with the highest net present value or benefit-cost ratio is selected. CBA requires the setting of a baseline against which costs and future expected benefits will be measured. This is challenging because it requires predicting autonomous adaptation behaviour by individuals and organizations in the absence of the option.	Does not explicitly deal with uncertainty, but can be combined with probabilistic information to generate expected values.	Economic (dollars)	Medium
Cost-Effectiveness Analysis (CEA)	This method identifies the most economically efficient option to achieve a specific adaptation goal (e.g., Boyd and Walton, 2006): for instance, which of several options alleviates the risk of water shortages at the lowest cost, or how much of the risk can be alleviated for a given expenditure. CEA is useful when the primary benefit metric cannot be expressed in monetary terms. However, as it can only be used to compare options in relation to a single benefit metric (e.g., cubic metres of water), it is generally not possible to appraise options that address impacts across different sectors that do not have a common benefit metric.	Does not explicitly deal with uncertainty, but can be combined with probabilistic information to generate expected values.	Quantitative	Medium

TOOL	SUMMARY	UNCERTAINTY	BENEFIT METRIC	COMPLEXITY
Cost-Effectiveness Analysis (CEA) (continued)	As with CBA, this method requires the setting of a baseline. In contrast to CBA, it cannot say whether an option is "worth doing"—the starting premise for applying CEA is that a decision has already been taken and that the outcome to be achieved has already been justified as "worthy" of pursuing.			
Multi-Criteria Decision Analysis (MCDA)	This method uses multiple metrics, in addition to economic efficiency, to assess adaptation options in terms of achieving specified adaptation goals (e.g., de Bruin et al., 2009b). MCDA is useful when it is difficult to assign monetary values to one or more outcomes of importance, or when it is simply not possible to quantify some outcomes, as qualitative and quantitative information can be combined. As with CBA, this method requires the setting of a baseline.	Can incorporate uncertainty as an evaluation criterion, typically relying on the subjective judgement of experts or stakeholders.	Economic, quantitative or qualitative	Low to medium

Source: Rouillard et al., 2016a; Watkiss et al., 2015a; Boyd et al., 2013; PROVIA, 2013; Watkiss and Hunt, 2013.

6.6.4 Key methodological challenges

Key methodological challenges related to the economic appraisal of adaptation actions include how to handle uncertainty in economic appraisal, discounting choices and distributional considerations. Because of these challenges, the literature is skeptical about relying mainly on traditional economic appraisal tools to rank adaptation actions (e.g., Dennig, 2018; Lempert, 2014; Li et al, 2014).

6.6.4.1 Handling deep uncertainty

When appraising adaptation actions, climate-related uncertainties arise from both climate modelling and socioeconomic aspects (*see* Figure 6.10). These are in addition to the usual uncertainties about the costs and effectiveness of actions that are present in all economic appraisals. The point of departure is the unknown path of future GHG emissions, which feed into climate projections through climate models. The specification of the relationships between projected emissions and projected changes in the global climate is subject to uncertainty, and different models resolve this in different ways. Most models provide projections at a scale that is too broad to be used for assessing actions at the local level, where adaptation generally takes place. Some downscaling must be done, which creates additional uncertainties. In addition, uncertainty arises from socioeconomic scenarios, which provide a range of estimates for populations at risk in different locations, and also take into account socioeconomic status and wealth. These scenarios are linked to GHG emissions since the latter will in part influence future living standards, and also because different development pathways will influence the amount of GHG emissions. These elements, however, are highly uncertain, especially over the time frames that most analyses need to consider. Finally, there are uncertainties regarding the effectiveness of different adaptation actions. In short, uncertainties "balloon" along the impact chain from GHG emissions to adaptation choices (*see* Figure 6.2).

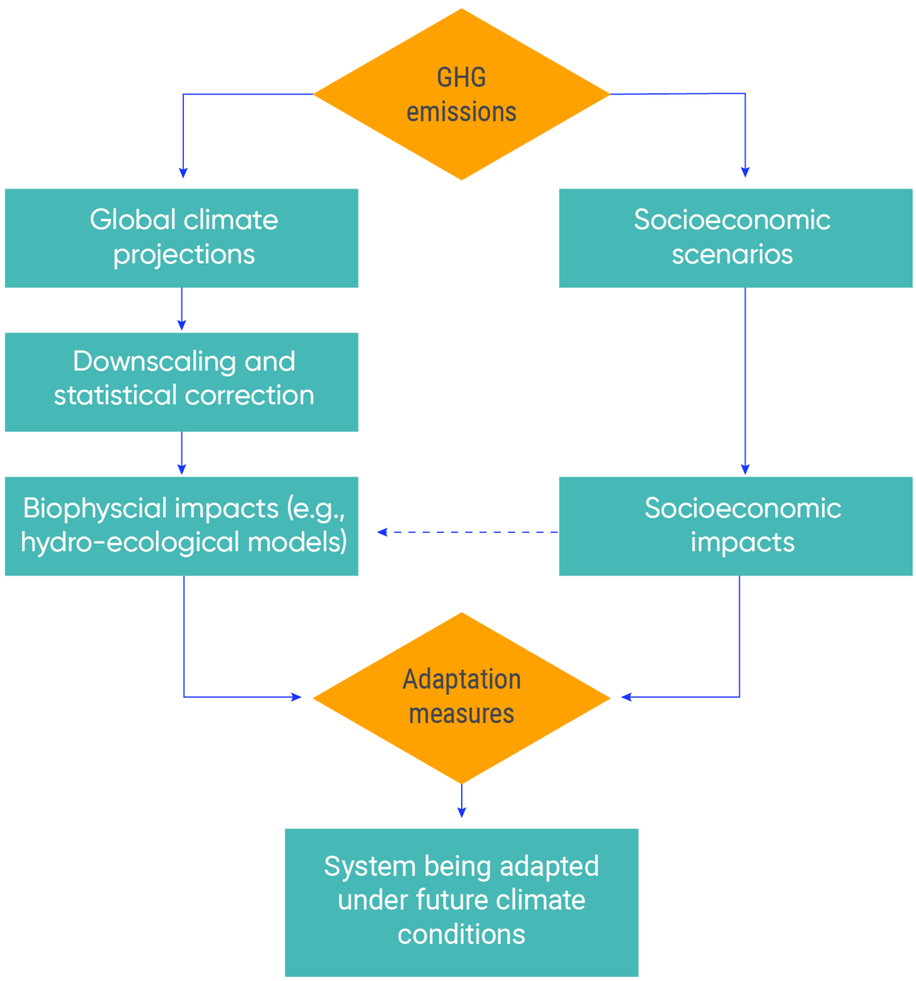


Figure 6.10: The structural elements involved in assessing climate change impacts and adaptation.
Source: Adapted from Markandya et al., 2014.

If the range of possible outcomes can be represented by a probability distribution, one can calculate an expected value. A "risk value" or "premium" can also be calculated, including a component to account for there being a range of possible outcomes. Methods for doing this are well established (e.g., Ranger et al., 2010). The problem is that such probability distributions are rarely available, and it is frequently not possible to calculate the risk value. When probabilities are not available, the traditional practice is to undertake a sensitivity analysis, which involves using scenarios to identify the robustness of the chosen adaptation action in relation to the dominant uncertainties.

While many of the uncertainties described above are reducible, there is little prospect that they will be resolved in a time frame that is useful for early adaptation decisions (Fankhauser, 2017). As a result, scholars have developed a range of heuristics (e.g., Hallegatte et al., 2012) and appraisal tools (e.g., Bloemen et al., 2018; Dittrich, et al., 2016; Watkiss et al., 2015a; Lempert, 2014; Walker et al., 2013) to support adaptation decision making in the presence of deep uncertainty (i.e., uncertainty that cannot be quantified with probabilities) (Weaver et al., 2013). The main approaches for accommodating uncertainty in the economic appraisal of adaptation actions include real options analysis (ROA), adaptation pathways, robust decision making (RDM) and portfolio analysis. See Table 6.5 for a brief description of each tool, how it deals with uncertainty and measures benefits, the resource demands that it places on users, and an example application.

Table 6.5: Economic appraisal methods for adaptation decision support under uncertainty

DESCRIPTION	UNCERTAINTY	BENEFIT METRIC	COMPLEXITY	EXAMPLE(S)
Robust decision making (RDM)				
Uses quantitative models/scenario generators to evaluate how different adaptation options perform under large ensembles of scenarios, each reflecting different plausible future conditions (both climate and socioeconomic). The goal is to identify options that are robust to many different futures (i.e., options that are not necessarily "optimal", but "good enough" and that minimize negative outcomes). This tool is useful when future uncertainties are poorly characterized and probabilistic information is not available.	Explicitly incorporates uncertainties and risks—particularly systemic risks—to derive solutions that are robust to multiple future conditions	Quantitative or economic	Medium to high	Lempert et al., 2013; Dessai and Hulme, 2007

DESCRIPTION	UNCERTAINTY	BENEFIT METRIC	COMPLEXITY	EXAMPLE(S)
Portfolio analysis				
Traditionally used to evaluate trade-offs between returns on an investment and the riskiness of that investment. In a climate change adaptation context, the trade-off is between the likelihood of a high degree of effectiveness in reducing a threat and the risk that the options under consideration will fail to be effective under certain future conditions. This tool helps to identify the set of options that, collectively, are effective over a range of plausible future conditions, as opposed to one option that is optimal for one future. It is useful when there are many complementary adaptation options available to achieve a goal and when good data is available. It requires probabilistic information to compute the variance of returns (net present values) across the portfolio of options under consideration.	Deals explicitly with uncertainty by examining the complementarity of a mix of adaptation options for dealing with future conditions	Quantitative or economic	High	Hunt, 2009

DESCRIPTION	UNCERTAINTY	BENEFIT METRIC	COMPLEXITY	EXAMPLE(S)
Real options analysis (RDA)				
Used to explicitly assess the level of flexibility in the timing for implementing one or more adaptation options (i.e., whether to invest now or wait). It is also used to assess the flexibility for adjusting an adaptation option over time, once it has been implemented (e.g., allowing an option to scale up or scale down in response to changing conditions or as new information becomes available). In this way, the tool reveals whether it is better to invest in options that offer greater flexibility in the future.It is useful for adaptation decisions involving large, upfront and irreversible investments, where there is flexibility in the timing of the investment, opportunity for new information to emerge, and the ability to adjust the option in response to learning.	Deals explicitly with uncertainty by analyzing the performance of adaptation options related to different potential future conditions	Economic	High	Jeuland and Whittington, 2013; van der Pol et al., 2013; Woodward et al., 2011

DESCRIPTION	UNCERTAINTY	BENEFIT METRIC	COMPLEXITY	EXAMPLE(S)
Adaptation pathways				
Used to operationalize the criterion of flexibility by characterizing adaptation options in terms of: 1) "adaptation turning points" (i.e., points in time beyond which options are no longer effective); and 2) what alternative adaptation options are available once a turning point has been reached. Rather than taking an irreversible decision now to implement an "optimal" adaptation option—which may or may not actually be needed depending on how future climate conditions evolve—this tool encourages decision makers to adopt a flexible plan, where adaptation decisions are made over time and the plan is adjusted as pertinent information emerges. Additional options can be brought forward or delayed to a later time, depending on future conditions. The main challenge relates to defining appropriate "turning points" and data to monitor.	Deals explicitly with uncertainty by promoting iterative analysis, monitoring, evaluation, learning and adjustment	Quantitative or economic	Medium to high	*See* Case Story 6.4; Rosenzweig and Solecki, 2014; Haasnoot et al., 2013; Ranger et al., 2013
Source: Rouillard et al., 2016a; Scussolini et al., 2015; Watkiss et al., 2015a; Boyd et al., 2013; PROVIA, 2013; Watkiss and Hunt, 2013.				

The most appropriate appraisal method depends on the decision-making context and the level of uncertainty (Chambwera et al., 2014). Choosing an economic appraisal tool could itself be viewed as a decision problem. For instance, in decision contexts where uncertainty is less of an issue (perhaps relevant probabilities are known) and where adaptation actions are short-term (i.e., low-regret and no-regret actions to address current climate risks), it may be possible to apply traditional CBA or CEA. When uncertainties are deeper, however, and when considering choices among a range of complementary actions to achieve the same adaptation goal, portfolio analysis can be used to help decision makers evaluate trade-offs between the benefits of an action and the riskiness of that action, thereby formulating a portfolio of actions that strike the best balance between risk and return. When uncertainties are anticipated to reduce over time and where individual actions or an adaptation strategy have some degree of flexibility, approaches that support iterative decision making will be more appropriate (such as ROA and adaptation pathways). These approaches encourage decision makers to develop flexible plans where the most efficient adaptation decisions are made sequentially over time, as evidence emerges on how future conditions are evolving. If there is little prospect for uncertainties to be resolved—where decisions are required in the short term with respect to long-lived adaptation actions—then RDM will provide appropriate decision support, helping to identify adaptation actions that achieve the decision maker's goals under a range of different futures.

While the above economic appraisal methods have been presented individually, they are not mutually exclusive. All of the available tools to support adaptation decision making under uncertainty essentially provide an alternative framing for the application of CBA, CEA, MCDA or some combination thereof. This is demonstrated in Case Story 6.4, where CBA and MCDA are embedded in an adaptation pathways approach to flood management on the Thames River in London, UK.

Case Story 6.4: Managing uncertainty in the appraisal of adaptation options for addressing sea-level rise in London, UK

The Thames Barrier is a movable structure that spans roughly 500 m across the River Thames, east of London. It is part of a comprehensive flood management system, comprising 36 industrial gates and over 330 km of floodwalls and embankments that protect London from storm surge from the North Sea. The Barrier was designed to last until 2030 and to provide a high standard of protection (equivalent to a one-in-1,000-year event). The goal of the Thames Estuary 2100 (TE2100) project was to develop a strategic flood risk management plan for London that would be in place until the end of the 21st century.

Owing to deep uncertainty surrounding future extreme water levels in the Estuary with climate change and the long-lived nature of the decisions involved, and with high irreversible costs, TE2100 used an adaptation pathways approach. This method integrates dynamic robustness (flexibility) to climate and non-climate uncertainties into the adaptation strategy itself, such that the strategy adapts to climate over time, but with individual actions left open to deal with the full range of plausible futures. Four potential packages of adaptation actions—referred to as "High-level Options" (HLO1, 2, 3a and 3b, and 4)—were developed by TE2100 (*see* Figure 6.11). Each HLO consists of a pathway through the century that can be adapted to the rate of change of observed sea-level rise. For example, under HLO1, sea-level rise of 20–30 cm would require improving and raising smaller walls and embankments on the Thames to extend their operational lives. If sea levels increased by 60–70 cm, the existing Barrier would be over-rotated, and interim (high wall) protection upstream of the Barrier would be restored. If sea levels rose by 80–90 cm, however, the existing Barrier would need to be improved and downstream defenses raised. Overall, HLO1 provides protection for up to about 2.3 m of sea-level rise, which is the "most probable" current projection of sea-level rise affecting extreme water levels in the Thames. HLO4, which culminates in the construction of a new barrage, would provide protection for the "worst-case" current projection of sea-level rise (4.3 m).

It would be risky, however, to select one pathway based on the projections available today, since the current choice of adaptation path is extremely sensitive to mean sea-level rise and storm surge projections, which are highly uncertain. The risk of maladaptation would be high. Therefore, the HLOs are designed to be flexible, and it is possible to move from one HLO to another depending on the rate of sea-level rise experienced.

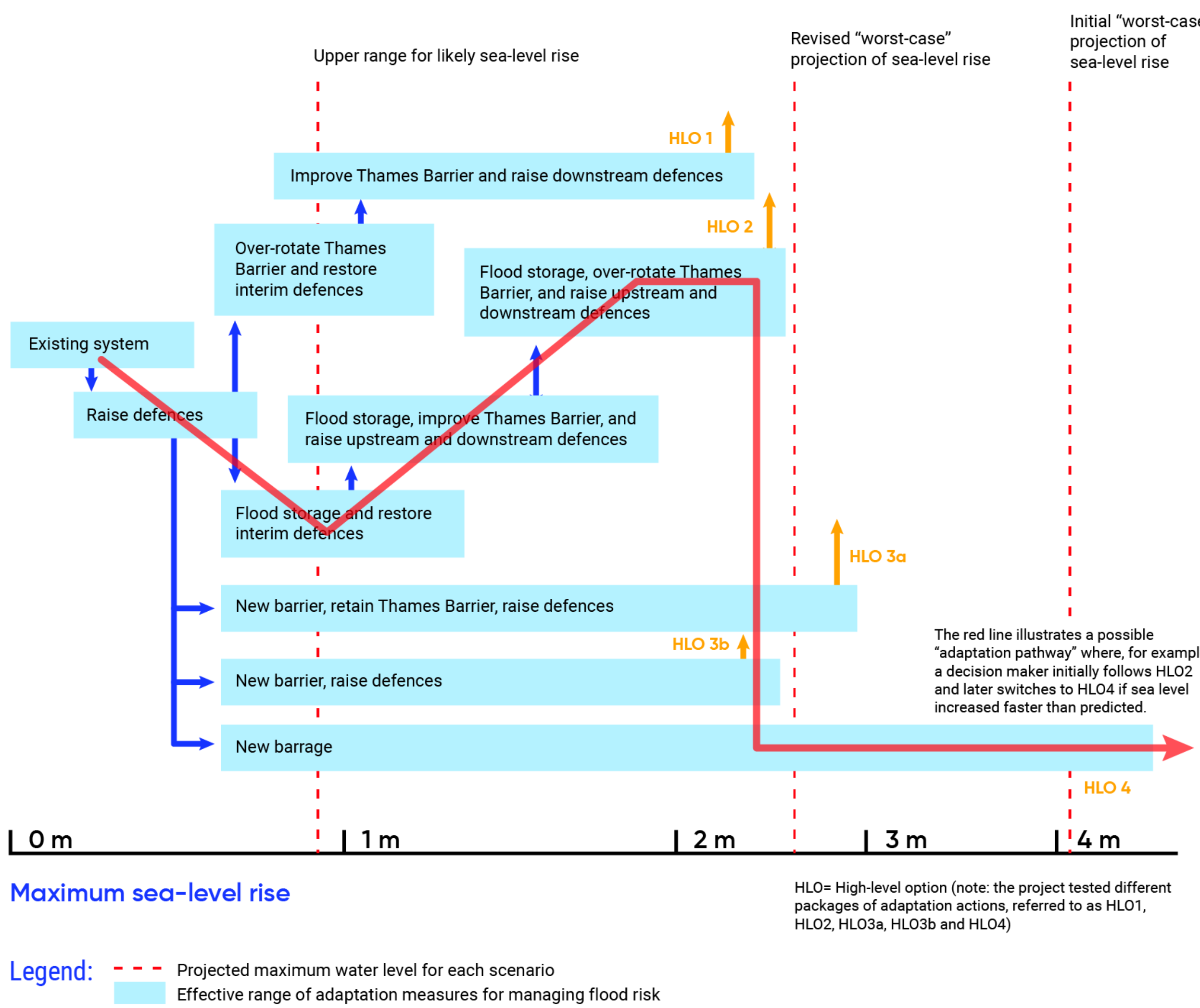


Figure 6.11: Adaptation pathways developed by the Thames Estuary 2100 project in the UK to address future sea-level rise. This includes four packages of adaptation options, referred to as "high-level options", for addressing different possible increases in sea level rise. Source: Adapted from Ranger et al., 2013 with permission from Springer Nature Customer Service Centre GmbH.

Crucial to the adaptation pathways approach is the need to define "decision points" in advance of a climate change impact taking place (i.e., to identify future times when decision makers will need to choose a more irreversible option, as well as the information needed to inform that decision). For each adaptation action, the TE2100 project assessed the following (*see* Figure 6.12): the key threshold at which that action would be needed (e.g., extreme water levels); the lead time required to implement the action; and the estimated decision point to trigger a decision regarding implementation (e.g., in terms of an indicator value being reached—such as observed extreme water levels—with an uncertainty range).

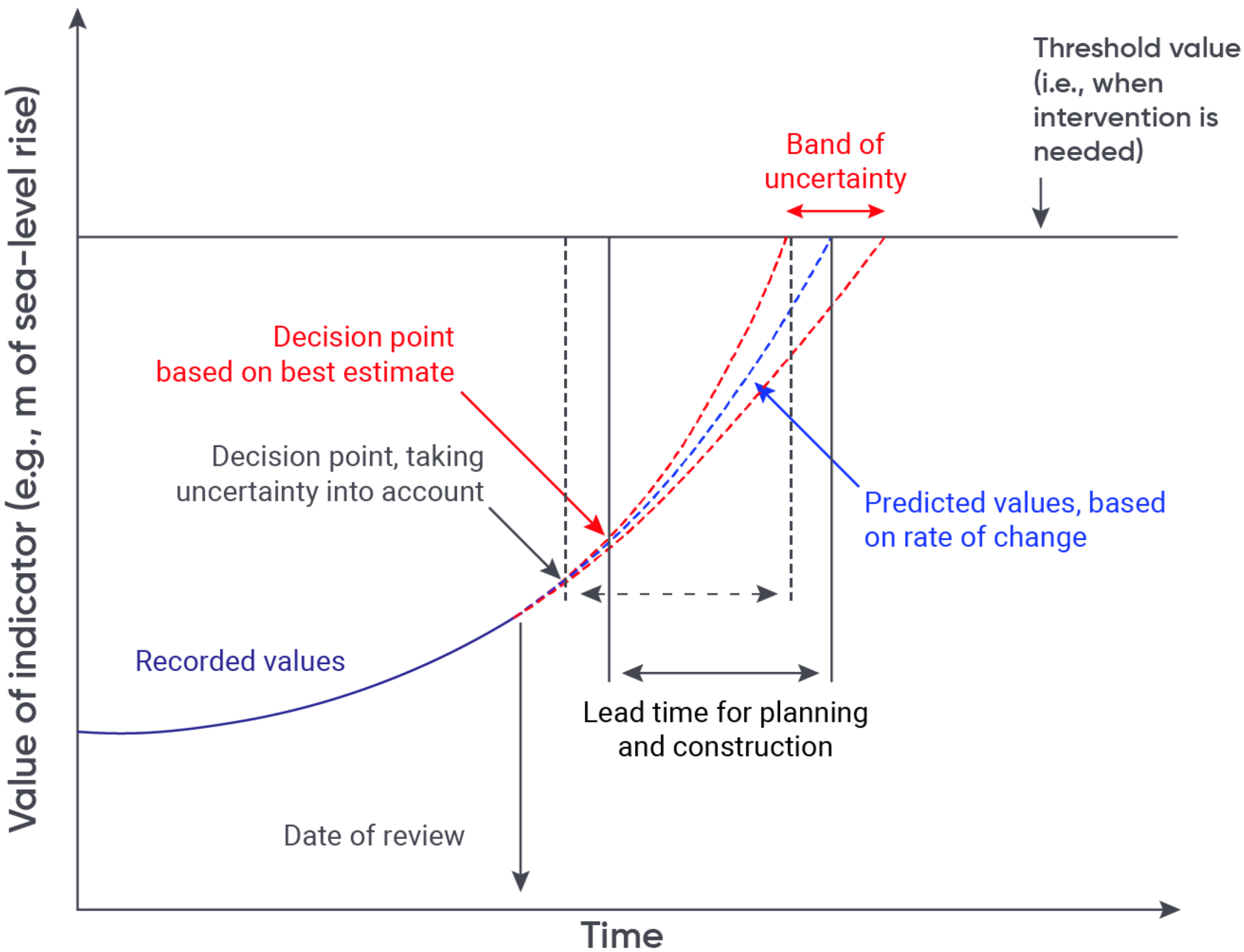


Figure 6.12: Illustration of the thresholds, lead times and adaptation decision points in the Thames Estuary 2100 project in the UK. Source: Adapted from Ranger et al., 2013, with permission from Springer Nature Customer Service Centre GmbH.

Each HLO and the associated individual actions were subject to a formal economic options appraisal, using a combination of CBA and MCDA. The appraisal included a range of readily monetized impacts (e.g., property damage, risk to life, loss of agricultural land) and non-monetized impacts (e.g., water quality and quantity, recreation, habitat and biodiversity, sense of community). Informed by the results of the appraisal, improving the existing system of protections—a low-regret measure—was recommended as the optimum approach for the first 60 years, with new options required by 2070 (based on current projections of sea-level rise) for 2100 and beyond. In the first iteration of the plan, to be reviewed in 10 years, all four HLOs remain open and are under consideration. However, due to the long lead-in time for the construction of some of the options that are needed by 2070, a decision on the preferred option must be made by 2050. This allows decision makers an additional forty years to accumulate knowledge about climate change and sea-level rise, and to gain a greater understanding of the uncertainties involved prior to committing to an irreversible and costly action. If monitoring reveals that extreme water levels (or another indicator, such as barrier closures) are increasing faster or slower than anticipated under current projections, the 2050 decision point may be brought forward or pushed back to ensure that decisions are made at the right time to allow for a cost-efficient response. Monitoring key indicators is important for the overall approach to be successful.

Two aspects of the application of traditional economic decision support tools in relation to climate change have been the focus of much critical debate: 1) the practice of discounting future economic consequences, and 2) valuing all contemporary consequences equally, regardless of who bears the costs or benefits (Dennig, 2018; Li et al., 2014).

6.6.4.2 Discounting choices

Adaptation actions will typically entail an upfront investment that yields a stream of benefits—and possibly costs—that do not occur in the same year as the investment, but rather are spread out over many years and even decades into the future. The practice of discounting (i.e., of assigning weights to future impacts) has been developed to assist with comparing costs and benefits that occur at different points in time (*see* Boyd et al., 2013 for a more in-depth review of this topic). Individuals acting on their own, as well as societies acting collectively, prefer to have something now rather than in the future[5]—in short, they give more weight to the present than to the future. The difference between the value of a dollar today and the value of a dollar in one year's time is referred to as an individual's or society's discount rate. This rate determines how quickly the weight-assigned future costs and benefits decline over time; the higher the rate, the less influence future costs and benefits have on present values. The discount rate is hugely instrumental in determining the weight assigned to future economic impacts (*see* Appendix 6.3 for more on the discounting process).

The choice of discount rate in climate policy analysis has been the subject of much debate among economists, though primarily in the context of GHG emissions reduction (e.g., Markandya, 2019; Stern, 2008; Nordhaus, 2007). The debate has focused on what rate to apply and, more recently, on whether that rate should be constant over time. On the first question, there is a distinction between the "prescriptive approach" and the "descriptive approach" (Arrow et al., 1996). The former—often referred to as the social discount rate—is based on what rate should be applied on ethical and policy grounds, while the latter—often associated with the opportunity cost of capital—is based on rates applied in the decisions that businesses

5 Strictly speaking, there are two main rationales for giving less weight to future economic effects. One is based on consumption and the other on investment (Arrow et al., 2012). Regarding the former, individuals and society give less weight to the future because of the expectation that future generations will be wealthier and the welfare that they receive from additional consumption will decline as their level of consumption increases. In other words, society exhibits a time preference for current consumption over future consumption. The investment rationale takes the view that so long as society can earn a positive rate of return on investment, it can invest less than one dollar today to obtain a dollar of benefits in the future. In this case, the discount rate would be equated to the rate of return on investment. Each rationale leads to different discount rates.

and individuals make in their daily lives. Prescriptive rates are typically lower than descriptive ones, but there are also substantive differences between scholars as to what the prescriptive rate should be. For example, in the discussion on what rate to apply in deciding on targets for reducing GHG emissions, Stern (2006) advocates for a social discount rate of about 1.4%, whereas Nordhaus (2007) and Weitzman (2007) present arguments for rates in the range of 4–6%. Furthermore, a survey of 197 experts on the determinants of the social discount rate found a mean recommended long-term rate of 2.27% (Drupp et al., 2015). There was considerable disagreement on the value of the rate, as indicated by the range of values recommended by individual experts (with values ranging from 0–10%). However, 92% of experts were comfortable with social discount rates somewhere in the range of 1–3% (Drupp et al., 2015). The official social discount rate for CBA of proposed federal regulations in Canada, as recommended by the Treasury Board of Canada Secretariat (TBS), is 3% (TBS, 2007); this rate was still effective as of September 1, 2018. According to the TBS (2018), it is appropriate to use the social discount rate test when "a regulatory proposal primarily affects private consumption of goods and services and [the] proposal's impacts occur over the long term (50 years or more)." Still, even when the social discount rate is used in CBA, present values based on the opportunity cost of capital should still be presented.

Descriptive rates also vary a lot depending on the nature of the investment, the risks entailed and the opportunities for alternative investments in the country. From 1976 until the release of the CBA guidelines in 2007, the TBS required that federal departments use an annual real discount of 10% (Boardman et al., 2008), derived from market data. The revised guidelines, which are still effective today, recommend a discount rate of 8% per annum (TBS, 2007, estimated from market data by Jenkins and Kuo, 2007).[6] This rate is based on the weighted opportunity cost of capital from three sources—domestic private-sector investors, domestic private-sector savers and foreign savers—and is characterized as a descriptive approach, in contrast to the prescribed 3% "social" discount rate.

On the question of whether a discount rate should be constant over time, the view has gradually been shifting away from a single constant discount rate to one that declines over time (Howard and Sylvan, 2015). This is a major change in thinking, as the determination of the discount rate as described above assumes that the rate does not change over time—although there is no reason for this to be the case. Several scholars have presented arguments for why the discount rate should decline with time. For instance, there is evidence suggesting that individuals and societies do not discount the future at a constant rate, but rather that they adopt a declining or "hyperbolic" path (Gowdy, 2013; Kim and Zauberman, 2009; Settle and Shogren, 2004). Consider the following example: an individual is faced with two choices: 1) postponing consumption for one year from now, and 2) deferring an equal amount of consumption for one year from year 50 to year 51 in the future. While postponing consumption right now for one year might mean a lot to the individual, postponing it for one year in 50 years might not. The weight placed on an extra year in the future declines with time. However, the standard formula for constant discounting gives the same value to both types of postponement.

Other arguments, which are often technical in nature, have been made for declining discount rates relating to uncertainty about the future (e.g., Epper et al., 2011; Newell and Pizer, 2003; Sozou, 1998) or the "right" discount rate (e.g., Weitzman, 2001; Azfar, 1998).

6 Some of the assumptions used by Jenkins and Kuo (2007) to arrive at the rate of 8% have been questioned by Boardman et al. (2008), who suggest that it should be in the range of 2.5% to 4.7%.

This work has provided a compelling case for using declining discount rates (Arrow et al., 2014, 2012; Cropper et al., 2014), especially when deciding on investments with long lifetimes (i.e., 30–50 years). It is important to maintain as much consistency as possible, however, in the way that discount rates are used. It is noteworthy that both the United Kingdom and France have shifted to declining discount rate schedules for the economic appraisal of public investments (*see* Figure 6.13). Boardman et al. (2008) propose a declining social discount rate schedule for intergenerational, public investments in Canada with lifetimes greater than 50 years: discount costs and benefits at 3.5% per annum from year 0 to year 50, 2.5% per annum from year 51 to year 100, 2.0% per annum from year 100 to year 200, and 1.5% per annum from year 200 onwards.

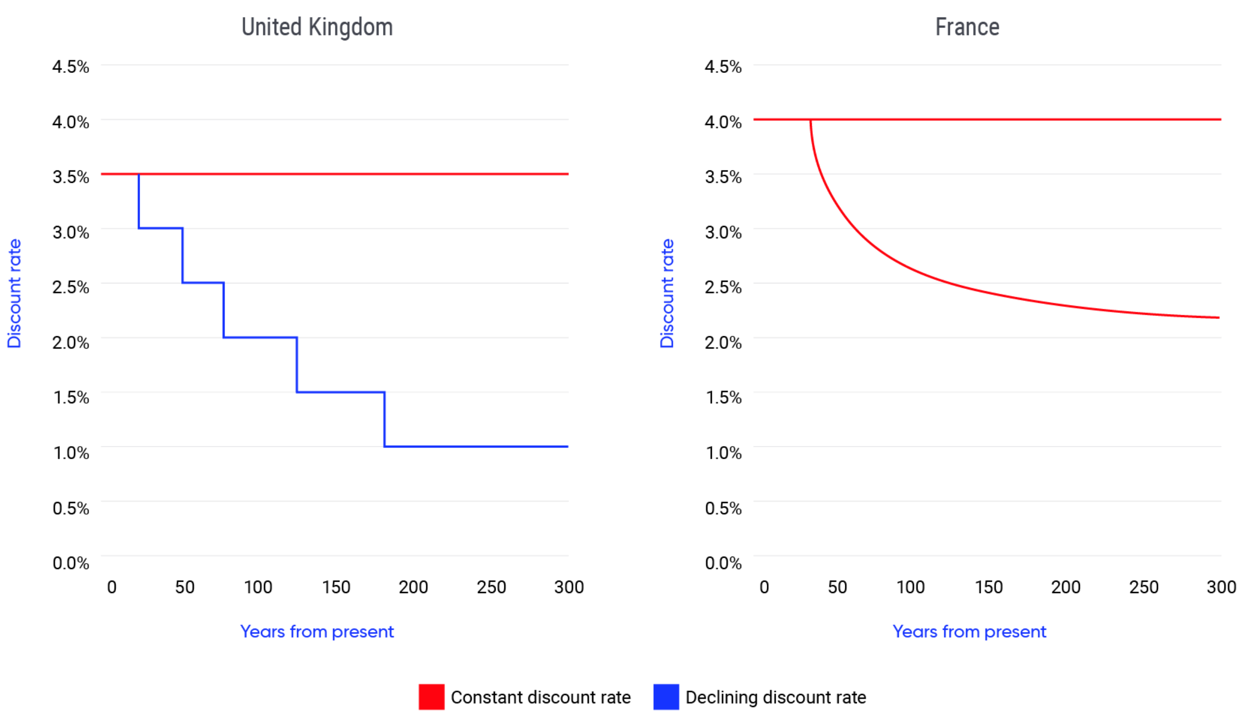


Figure 6.13: Declining social discount rate schedules in practice in the UK and France. The solid red line shows the social discount rate if it were assumed to be constant over time, whereas the solid blue line shows the schedule of declining discount rates used to appraise public policies, programs and projects in each country. The social discount rate schedule for the United Kingdom declines in discrete steps from 3.5% per annum to 1% per annum. In France, the official rate begins to decline after 30 years, following a hyperbolic path. In both countries, the discount rate to be applied to benefits in year 200 is lower than the rate for year 100. As a result, more weight is being assigned to the future rather than applying a constant discount rate to benefits in all years. Source: Adapted from Damon et al., 2013.

Across available examples of the economic appraisal of adaptation actions in Canada (*see* Appendix 6.4), present values are determined using a discount rate of 3–4% per annum. This implies that studies are using a social or “prescriptive” discount rate. The discount rate is also kept constant over time, even over time horizons of 50 to 100 years.

The choice of discount rate and schedule may not be as critical an issue for appraising adaptation investments as it is for investments in GHG emissions reduction. With the increasing emphasis on early adaptation, and the timing and sequencing of adaptation actions, time horizons for adaptation decisions can be relatively short—typically involving costs and benefits spread over decades, rather than centuries, as with the benefits of GHG emissions reduction projects. For “flow” adaptation actions[7], the costs and benefits will fall in the same time period. Furthermore, for most public and private sector decision makers, the discount rate will already be prescribed for specific decision contexts. When contrasting the economic performance of multiple actions to achieve the same adaptation goal that has been appraised using different discount rates, it is important to understand how the different discounting decisions influence the results to avoid “comparing apples and pears.”

6.6.4.3 Distributional considerations

When it comes to aggregating costs and benefits, the standard approach has been to apply equal weights to impacts experienced by diverse actors. This can present decision makers with a different set of distributional concerns, since all potentially exposed actors are not equally at risk. For instance, low-income and disadvantaged groups are often more vulnerable to climate change impacts and have reduced capacities to adapt. From a public policy perspective, it is important to include the distribution of the costs and benefits of adaptation in decision making. The Canadian Cost-Benefit Analysis Guide published by the TBS (2007)—which requires federal departments to analyze the costs and benefits of proposed regulations—explicitly refers to the need for distributional analysis: “Distributional analysis determines the impact of the regulatory proposal on affected stakeholders by category, such as—but not limited to—business size (small, medium-sized and large businesses), income, age, region and gender. Departments are to perform distributional analysis to assess how the estimated costs and benefits are distributed among stakeholders” (TBS, 2018).

Adaptation actions would, of course, be no exception to such a requirement. While trade-offs between an action’s net present value and its distributional impacts remain a political consideration, the literature includes an approach that explicitly integrates distributional dimensions into the summary estimate of net present value. It does this by weighting the different benefits and costs to reflect society’s value of a benefit or cost to one income group relative to the average (*see* Appendix 6.5). This method of dealing with distributional considerations (e.g., Alder, 2016)—where estimated benefits or costs are multiplied by weighting factors that are inversely proportional to people’s income—dates back to the 1950s and was included in the first CBA manuals (Squire and van der Tak, 1975). While this method does not capture all distributional issues that could be of interest to decision makers, it does focus on income inequality.

7 Flow adaptation actions are typically low-cost, short-lived responses to climate change impacts, where the costs and benefits are borne in the same time period. They are generally flexible and can be readily scaled up or down, or modified. For instance, a farmer who chooses to plant new heat-resistant crops in response to the climate getting warmer exemplifies a “flow” adaptation. The farmer will incur the costs of the new seeds, and accrue the benefits in the same period (Felgenhauer and Webster, 2014; de Bruin, 2011).

In practice, it is rare for equity weights to be applied in traditional economic analysis (Li et al., 2014). None of the economic appraisals of adaptation actions in Canada examined in Section 6.7 consider distributional issues or the formal use of equity weights. In general, however, there is renewed interest in incorporating equity considerations into the economic appraisal of climate change impacts and adaptation (Dennig, 2018), and the application of equity weights is an established way to do it (Rouillard et al., 2016b).

6.7 The benefits of adaptation actions in Canada outweigh the costs

The benefits of planned actions to adapt to climate change in Canada generally exceed the costs, sometimes significantly, providing a strong business case for proactive investment in adaptation. Even when beneficial adaptations are adopted, residual damage costs are often still incurred, suggesting that there are economic limits to adaptation.

Studies of the costs and benefits of adaptation in Canada have used traditional cost-benefit analysis (CBA). Across a sample of 60 adaptation actions to address impacts such as coastal flooding, low water levels, reduced timber supply, heat stress and poor air quality, the average benefit-cost ratio was 5.6:1, with 75% of actions having a ratio greater than one. Across this sample, soft adaptation actions (e.g., changes to planning and pest control practices) performed better than hard engineered actions (e.g., dykes and sea walls). The economic performance of adaptation actions is also highly site-specific and context-specific. Adaptation does not generally cancel out all costs related to climate change costs—some level of residual damage cost is generally still incurred.

6.7.1 Economic analysis of adaptation options in Canada

The body of literature on the appraisal of adaptation costs and benefits in Canada is limited to the public sector and a few climate-sensitive sectors; it therefore covers a narrow range of climate change impacts, regions and potential adaptation actions. This makes it difficult to form widespread generalizations about the costs and economic attractiveness of adaptation actions in all contexts. This section reviews the application in Canada of the methods discussed in Section 6.6.

6.7.1.1 Economic appraisals of adaptation

In general, while the body of evidence on the benefits and costs of climate change adaptation actions has increased significantly in recent years, its scope remains very narrow in terms of climate-sensitive sectors considered, the regional representation of economic studies, and the application of different economic appraisal methods. Nearly 75% of the individual adaptation actions appraised relate to the potential adoption of adaptation actions in coastal areas to address the risk of sea-level rise, storm surge flooding and erosion (*see* Case Story 6.5). It is worth noting that, while all the available studies perform prospective appraisals of potential adaptation actions that could be adopted, none provide retrospective appraisals of adopted actions. Several studies appraised adaptation actions to address the adverse impacts of low water levels on issues such as marine transport, hydroelectric generation, waterfront property prices, ecological services and fishing in the Great Lakes–St. Lawrence River system. The remaining studies performed economic appraisals of adaptation actions to address adverse climate change impacts on timber supply across Canada, heat stress and air quality in Toronto, snow conditions and length of the ski season at resorts in Quebec, and the functionality of a winter ice road in the Northwest Territories.

These studies clearly represent only a sub-set of climate-sensitive sectors in Canada; there are significant evidence gaps with respect to the economic appraisal of climate change adaptation actions for sectors such as transportation (rail, road and air), water resources (water security and quality), sanitation, energy (including electricity), fishing, agriculture, tourism, ecosystem services and human health. There is also a dearth of evidence on the benefits and costs of planned adaptation to climate-related health impacts, although impacts associated with human health can be some of the most economically significant. As the Larrivée et al. (2015) study for Quebec shows, the total present-value costs of premature mortality due to temperature extremes over the period 2015–2064—measured from a social perspective—were estimated at $33 billion (in 2012 dollars). When also considering Lyme disease, West Nile virus and aeroallergens, the total present-value cost rises to about $35 billion (*see* Appendix 6.1; Larrivée et al., 2015).

The concentration of accessible studies on a narrow set of sectors means that specific regions of Canada are well represented in the literature (e.g., coastal areas, particularly in Quebec and Atlantic Canada), while others are poorly represented. Except for the forestry sector, there are significant evidence gaps for the Northwest Territories, the Yukon and Nunavut, Ontario, the Interior of British Columbia and the Prairie provinces. Even though Alberta has historically experienced a disproportionate share of weather-related natural catastrophes in Canada (*see* Section 6.4.2), no accessible studies have examined the benefits and costs of adaptation to climate change in the province. Several studies have performed cost-benefit analyses of measures to reduce impacts from riverine flooding (e.g., IBI Group 2015a, b and c for the City of Calgary), although these studies make no reference to climate change.

There is also a scarcity of accessible literature on the benefits and costs of climate change adaptation actions in Indigenous communities. As part of the First Nation Adapt Program of Crown-Indigenous Relations and Northern Affairs Canada, a methodology was developed to provide department staff with guidance on how to assess the economic implications of continuing to meet the department's obligations with respect to Indigenous communities in the face of climate change (Girard, 2018). This methodology has been used to appraise the economic impacts of adaptation actions in two different decision contexts (Girard, 2018). The first considered the impact of projected warming on winter roads, and adaptation costs and benefits for the Northern Ontario winter road network. The second considered the costs and benefits of adaptation to coastal flooding from sea-level rise for Indian Island First Nation and Eel River Bar First Nation, both in New Brunswick. In the former context, the economic appraisal determined that building an all-season road network to service communities is economically inefficient compared with the status quo (i.e., winter roads plus emergency fuel subsidy funding), under all scenarios considered. In the second context, the appraisal concluded that investing in near-term flood reduction measures generated benefits that greatly exceeded the associated costs under all flood protection scenarios examined. Quantitative results were not available for these two studies.

In all studies summarized in Appendix 6.4, the appraisal of adaptation benefits and costs was performed using CBA. The available body of literature for Canada does not include applications of CEA or MCDA, or applications of new economic tools—such as RDM, ROA, portfolio analysis and adaptation pathways—to support adaptation decision making under uncertainty.

Case Story 6.5: Assessing the costs and benefits of adaptation options for coastal areas in Quebec and Atlantic Canada

Coastal settlements in Eastern and Atlantic Canada are vulnerable to erosion and flooding. Risks attributable to these hazards are anticipated to increase with climate change, threatening communities. To inform the business case for investing in adaptation measures, standard cost-benefit analysis (CBA) was used to appraise a range of adaptation actions at 11 case study sites (encompassing 46 smaller coastal segments) across Quebec and Atlantic Canada. These sites include Percé, Maria, Carleton-sur-Mer, Îles-de-la-Madeleine and Kamouraska in Quebec; the Chignecto Isthmus, which spans New Brunswick and Nova Scotia; the Halifax Harbour in Nova Scotia; the North Cape Coastal Drive and Provincial Park, and Tracadie Small Craft Harbour and Road in Prince Edward Island; and Bay Bulls-Witless Bay and Marystown in Newfoundland.

CBA—like all economic decision support tools—compares the costs and benefits of a "with project" scenario (i.e., what is anticipated to happen as a result of the adoption of an adaptation action) to those of a "without project" scenario (i.e., what is anticipated to happen if that adaptation action is not adopted). In this case, the "without project" scenario is given by the direct economic damage costs resulting from projected coastal flooding and erosion with climate change over a 50-year period (2015–2064), assuming no socioeconomic change (i.e., no population and economic growth) or additional adaptation actions at each site. Impacts with market and non-market economic consequences included in the assessment are shown in Table 6.6; not all impacts are relevant at all case study sites. The cost of adaptation actions included both investment expenditures and maintenance expenses; benefits reflected direct damage costs avoided plus the monetary equivalent of positive co-impacts generated.

A portfolio of suitable adaptation options was developed for each site, drawing from the following intervention categories:

- Hard-engineering structures (e.g., concrete walls, dykes, rock armour, riprap, sheet pile walls, seawalls, T-groynes);
- Soft-engineering structures (e.g., beach nourishment alone or in combination with groynes); and
- Preventative options (e.g., planned retreat of buildings, elevation of buildings and infrastructure, both of the previous interventions together, abandonment of parks).

Table 6.6: Economic costs and benefits included in the cost-benefit analysis of adaptation actions

TYPE OF SOURCE OF COSTS AND BENEFITS	COSTS ORIGINATING FROM NEGATIVE IMPACTS	BENEFITS ORIGINATING FROM POSITIVE IMPACTS
Related to erosion	Loss of land	
	Complete or partial loss of residential or commercial buildings	
	Loss of or damage to public infrastructure	
	Emergency evacuation	
Related to flooding	Damage to land	
	Damage to residential or commercial buildings	
	Damage to public infrastructure	
	Emergency evacuation	
	Traffic congestion or detour	
	Debris clean-up	
Economic	Reduced land value	
	Loss of goods and commercial revenues	
	Loss of trade	
	Loss of tourism revenues	Gain in tourism revenues

TYPE OF SOURCE OF COSTS AND BENEFITS	COSTS ORIGINATING FROM NEGATIVE IMPACTS	BENEFITS ORIGINATING FROM POSITIVE IMPACTS
Environmental	Loss of natural habitats	Improvement in fish spawning grounds
	Loss of fish spawning grounds	
Social	Loss of sea view	Improvement in the coast's recreational use
	Loss of sea access	
	Decline in the coast's recreational use	
	Reduced quality of life (anxiety, insecurity, etc.)	Improvement in quality of life (security, etc.)
	Deterioration in the landscape	Improvement in the landscape
	Deterioration in historical and cultural heritage	

Key

- Cost included by Quebec and Atlantic Canada
- Cost included by Quebec only
- Benefit included by Quebec only.

Source: Boyer-Villemaire et al., 2016

Two metrics of economic performance were generated through the CBA: 1) net present value (i.e., present-value benefits less present-value costs), and 2) the benefit-cost ratio (i.e., present-value benefits divided by present-value costs). Present values were calculated over 50 years (2015–2064) using a constant discount rate of 4% per annum (sensitivity analysis used rates of 2% and 4%). All costs and benefits are measured in constant 2012 dollars.

The results of the CBA (*see* Figure 6.14) suggest that implementing the best performing adaptation action at each coastal segment would result in net economic gains (i.e., the net present value is positive) in 27 of 46 segments (59% of cases). In these 27 coastal segments, the preferred intervention on average is not a hard- or soft-engineering measure, but rather a preventative option, such as a planned retreat, elevation of buildings and infrastructure, or the use of both an engineering measure and a preventative option in combination (*see* Figure 6.15). The large range of estimated net present values and the number of adaptation actions or segments falling within a particular performance group in Figure 6.14 suggest that both the decision to intervene and the choice of adaptation action cannot be generalized for application elsewhere. The economic case for adaptation action is greatly influenced by site-specific factors.

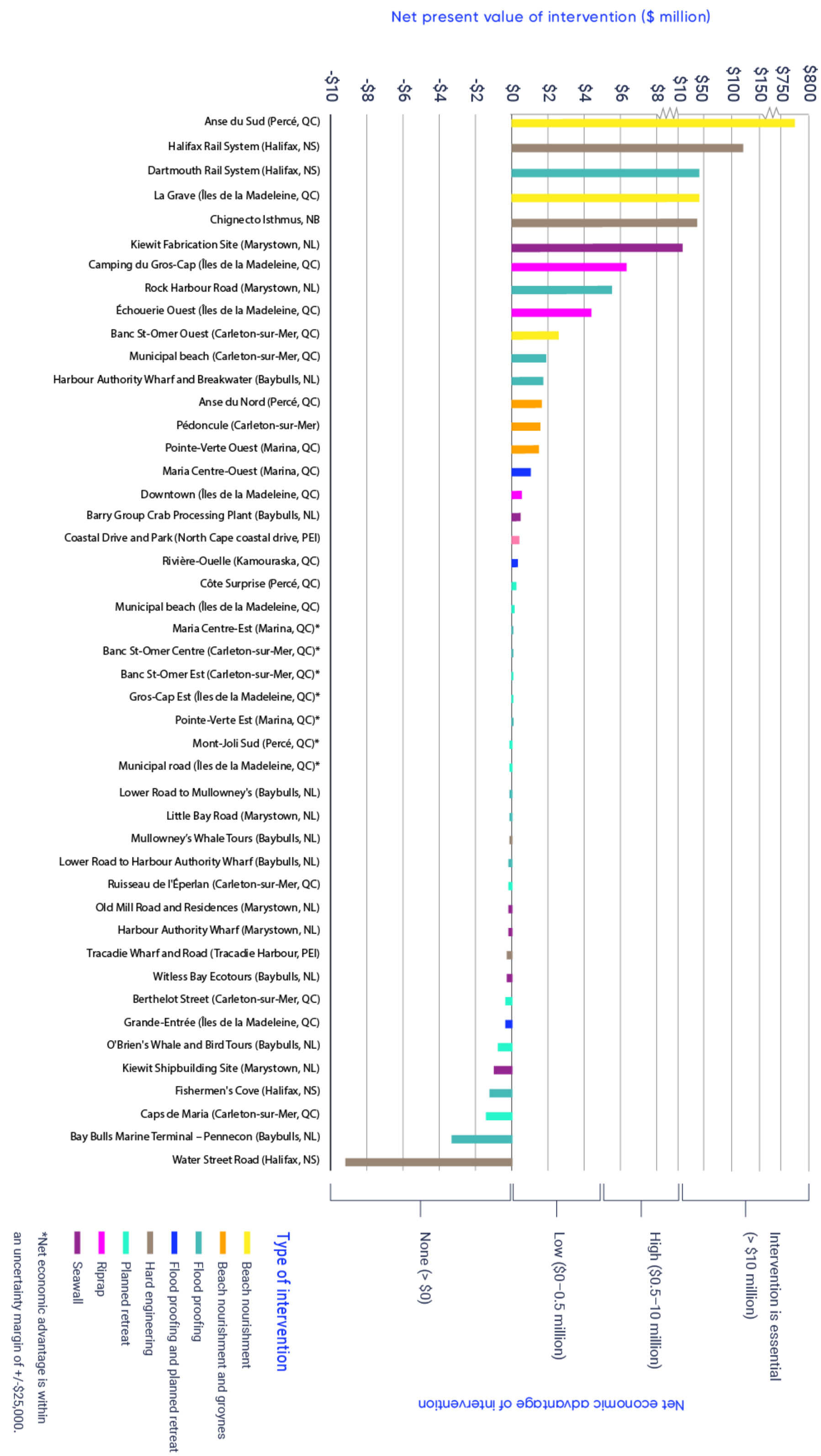


Figure 6.14: Net present values of the best performing adaptation actions for each of 46 coastal segments across 11 case study sites in Quebec and Atlantic Canada, listed from high (left) to low (right) economic advantage of intervention. Source: Adapted from Circé et al., 2016b.

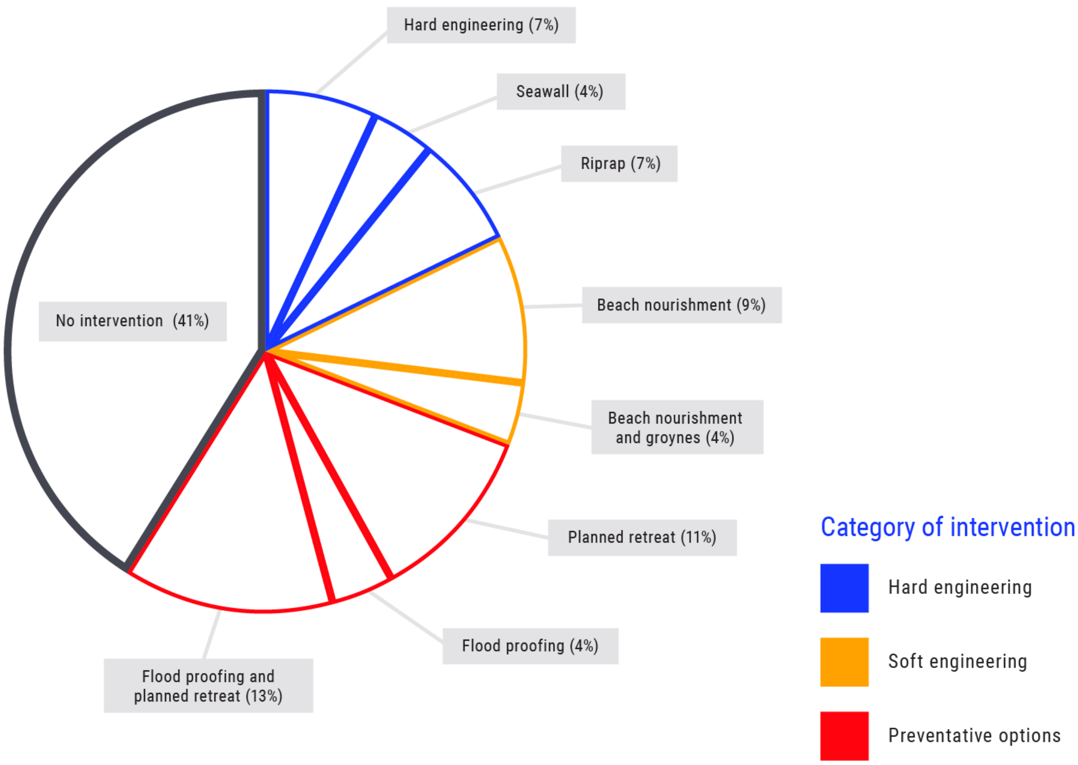


Figure 6.15: Distribution of the best performing adaptation actions by category of intervention, based on a cost-benefit analysis of 46 coastal segments across 11 case study sites in Quebec and Atlantic Canada. Source: Adapted from Boyer-Villemaire et al., 2016.

Case Story 6.6: Considering co-benefits in the economic appraisal of adaptation actions for water retention at Pelly's Lake, Manitoba

Pelly's Lake is a naturally occurring retention basin near Holland, Manitoba, that flows into the Boyne River, a tributary of the Red River, which has a history of significant flooding. Fertile agricultural lands surround the lake, producing a range of crops, including canola, spring wheat, alfalfa and barley. The water storage capacity of the lake is 2.1 million m^3, making it a large water source for irrigation to help farmers manage the risk of variable precipitation with climate change. In 2017, researchers from the University of Saskatchewan performed an economic assessment of adaptation actions involving Pelly's Lake (Moudrak et al., 2018; Berry et al., 2017a, b), with the goal of reducing water stress on agricultural crops by supporting irrigation during periods of drought under different emissions scenarios (RCP2.6, RCP4.5 and RCP8.5).

Projected changes in precipitation and temperature (based on ensemble mean values from four downscaled General Circulation Models obtained from the Pacific Climate Impacts Consortium) were input into an integrated "hydrological-reservoir-irrigation-plant growth" economic model of the watershed, developed from 2005–2014 data. Projections of aggregate crop gross margins, with and without irrigation, were made for two future time periods: the 2050s (10-year average over 2050–2059) and the 2090s (10-year average over 2090–2099). On average, compared to the "no irrigation" case, projected future gross income (in 2015 $ per hectare) with irrigation increased by about $12.1 (RCP2.6), $14.4 (RCP4.5) and $13.5 (RCP8.5) in the 2050s, and by about $14.3 (RCP2.6), $13.4 (RCP4.5) and $11.8 (RCP8.5) in the 2090s. This suggested that crop yields increased with irrigation. However, when the investment and maintenance costs of the irrigation system are taken into account, the difference in gross margins (for the "with irrigation" case less those for the "no irrigation" case) is consistently negative for both time periods across all three emissions scenarios. For example, projected gross margins with irrigation in the 2090s are about $146–$148 per hectare lower than gross margins without irrigation. Even though the availability of irrigation water increases crop yields, the corresponding increase in gross income is insufficient to compensate for the costs of the irrigation system.

The water retention system at Pelly's Lake provides a range of services, in addition to storing water and supporting crop irrigation. The system can be used for biomass (cattail) production and nutrient retention, thereby reducing downstream nutrient and sediment loading. It can also sequester carbon and capture excess spring runoff and rainfall from extreme precipitation events—the latter reduces potential flood risks downstream. These positive co-benefits have been valued at about $25,505 per hectare per year.

Use of the multi-purpose water retention system at Pelly's Lake as an adaptation measure to help farmers manage risks related to water stress under climate change conditions does not pass a standard cost-benefit test, when considering only the irrigation benefits provided to participating farmers. However, if the range of co-benefits provided by the system were to be included in the analysis, the system would be deemed economically viable as an adaptation measure. The private co-benefits provided by the system—if monetized—would be enough to create a business case for farmers to invest in irrigation, while providing wider economic and environmental benefits to the region.

6.7.1.2 Cost of adaptation

Appendix 6.4 provides some information on the estimated cost of adaptation options, which serve as inputs to cost-benefit analyses. In general, understanding of the cost of climate change adaptation in Canada is in its infancy. Two recent studies, however, have sought to address this knowledge gap. The Insurance Bureau of Canada and the Federation of Canadian Municipalities (2020) estimate that $5.3 billion dollars (in 2019 dollars) need to be invested annually, on average, over a 50-year planning horizon to adapt Canadian public infrastructure (e.g., roads, dykes, water treatment facilities, sewer systems, etc.) to climate hazards. This is equivalent to about 0.26% of national GDP per year. This level of spending on climate change adaptation is consistent with large cities internationally; for example, actual expenditure on climate change adaptation in London, New York and Paris in 2014–2015 amounted to 0.22–0.23% of the GDP for these cities (Georgeson et al., 2016). In terms of individual climate hazards and types of infrastructure, reducing flood risk and investment in grey infrastructure (such as buildings, dykes, roads, etc.), respectively, were associated with the highest levels of expenditures. Regionally, planned annual expenditures on climate change adaptation in Atlantic Canada account for about two-thirds ($3.6 billion) of the national total. The relative cost at a regional level should be viewed with caution, however. The above results are derived from a database of over 400 cost estimates from the climate change adaptation plans of 34 communities across Canada (Insurance Bureau of Canada and Federation of Canadian Municipalities, 2020). Some regions of Canada are underrepresented (such as British Columbia and Nunavut), as are mid-sized urban centres, while other regions (Alberta) and small population centres are over-represented. Furthermore, the adaptation planning process used by the 13 Alberta communities (40% of the sample) in the database encourages prioritization of no-regret and low-regret "soft" measures, with low investment requirements. For these reasons, and the fact that the adaptation actions costed in the community plans likely focus on the top-priority climate risks—and not all risks—the estimated expenditure of $5.3 billion per year is likely an underestimate of the needed investment in adaptation.

A further recent study estimated the required expenditure to adapt municipal infrastructure in Quebec for climate-related risks at $2.8–$5.4 billion (2019 dollars) over the next five years (AGECO Group, 2019).[8] This is equivalent to about 0.12–0.23% of GDP annually. Again, the full scale of the required investment in adaptation is likely underestimated, since only a sub-set of public infrastructure is included in the analysis—specifically, water assets (drinking water, sanitation and drainage), green infrastructure and roads.

6.7.2 The economic case for adaptation

To help draw conclusions regarding the economic case for climate change adaptation from the available studies listed in Appendix 6.4, adaptation actions where a benefit-cost ratio (BCR) was reported or could be derived (60 actions in total) are rank-ordered and presented in Figure 6.16. A BCR is given based on the present value of benefits of an adaptation action, divided by its present value costs. As such, it controls for the scale of adaptation actions, thereby facilitating comparisons across actions of different size (other factors limiting comparisons are discussed below). A BCR greater than one indicates that an adaptation action's benefits exceed the costs incurred to generate those benefits—such an action would typically be a justifiable investment on economic efficiency grounds. However, not all actions with a BCR greater than one are necessarily implemented, as their implementation depends on a range of factors, including available resources (*see* Section 6.8.1).

Figure 6.16 shows that, across the 60 adaptation actions, 75% pass a cost-benefit test. The unweighted average BCR is 5.6 (i.e., every dollar invested in climate change adaptation actions generates, on average, $5.60 in benefits). The average BCR is heavily skewed by a handful of extremely high values, however. The unweighted median BCR is 1.5, and half of the values lie between 0.9 and 2.7. These values are consistent with international experience—for example, in a review of a statistical sample of the nearly 5,500 Federal Emergency Management Agency (FEMA) grants in the U.S. awarded between 1993 and 2003 for addressing

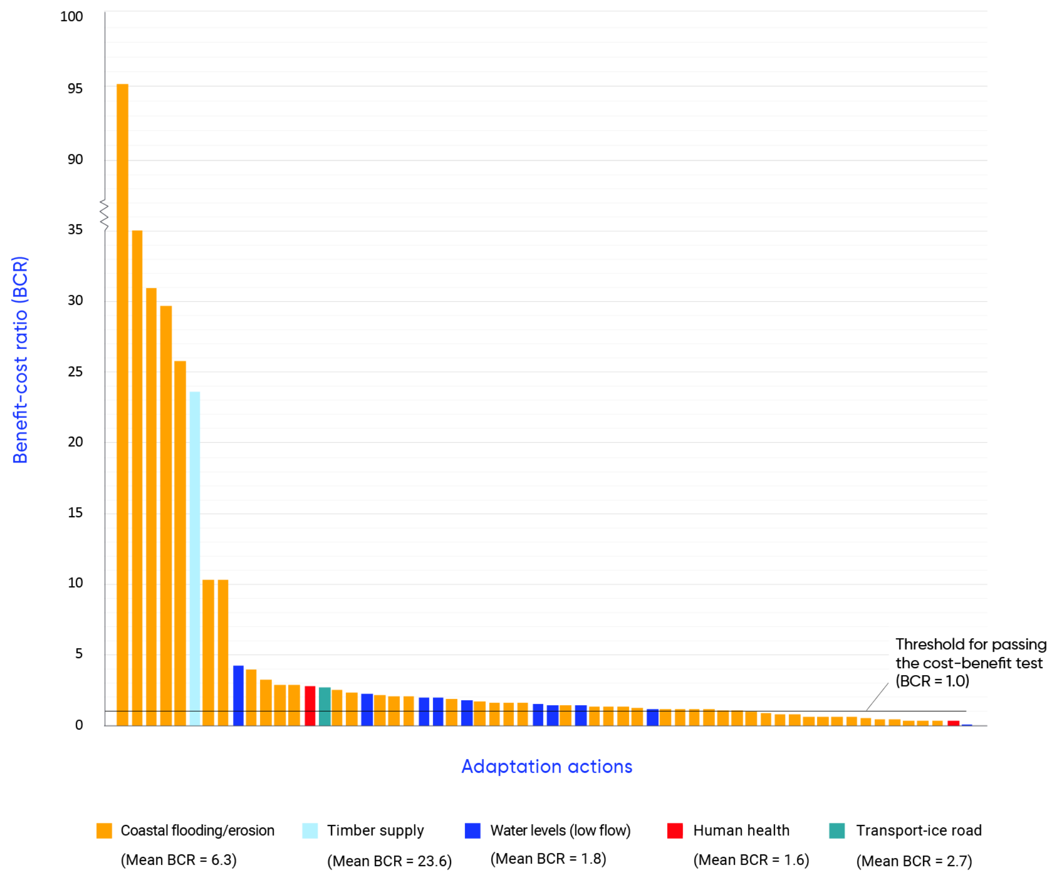
8 There may be some overlap with the cost estimate by the Insurance Bureau of Canada and Federation of Canadian Municipalities (2020) of $5.3 billion annually, which included four municipalities from Quebec.

earthquake, flood and wind hazards, Rose et al. (2007) found that the overall average BCR ratio was about 4.0, whereas the average BCR for flood reduction measures was 5.1. Likewise, the Global Commission on Adaptation found that $1 judiciously invested in climate change adaptation could generate $2–10 in economic benefits (Global Commission on Adaptation, 2019).

The available examples from the 60 adaptation actions suggest that "soft" adaptation actions (with a mean BCR of more than 10:1) represent more economically efficient investments than "hard engineering" adaptation actions (with a mean BCR of about 3:1). This is largely due to the higher upfront investment expenditures needed for the latter set of actions. It is also partly due to the inclusion of monetized co-benefits generated by some of the "soft" actions (specifically in the appraisal of coastal adaptation actions in Quebec) and to the inclusion of both direct and indirect benefits (i.e., avoided costs) in a couple of studies (e.g., timber supply) that examined only "soft" adaptation actions. As noted in Section 6.6.1, the economic performance of a project is only one of several important criteria for selecting adaptation options. In some cases, "soft" options may not offer an acceptable level of risk reduction, thus necessitating the adoption of "hard" options, which may have less attractive BCRs.

In general, the diversity of methodological choices makes comparing results across available appraisals of adaptation costs and benefits difficult. Studies use different time horizons, emissions scenarios and norms; they make different assumptions about socioeconomic development, and monetize different combinations of market and non-market impacts, co-benefits, and direct and indirect impacts (*see* Case Story 6.6). They also use different discount rates, though this is less of an issue regarding the comparability of studies, since nearly all apply constant rates of 3–4% per annum, which is indicative of a prescriptive rather than a descriptive approach to discounting (*see* Section 6.6.3.2).

a)


100
95
90
35
30
25
20
15
10
5
0
Benefit-cost ratio (BCR)
Threshold for passing the cost-benefit test (BCR = 1.0)
Adaptation actions
Coastal flooding/erosion (Mean BCR = 6.3)
Timber supply (Mean BCR = 23.6)
Water levels (low flow) (Mean BCR = 1.8)
Human health (Mean BCR = 1.6)
Transport-ice road (Mean BCR = 2.7)

b)

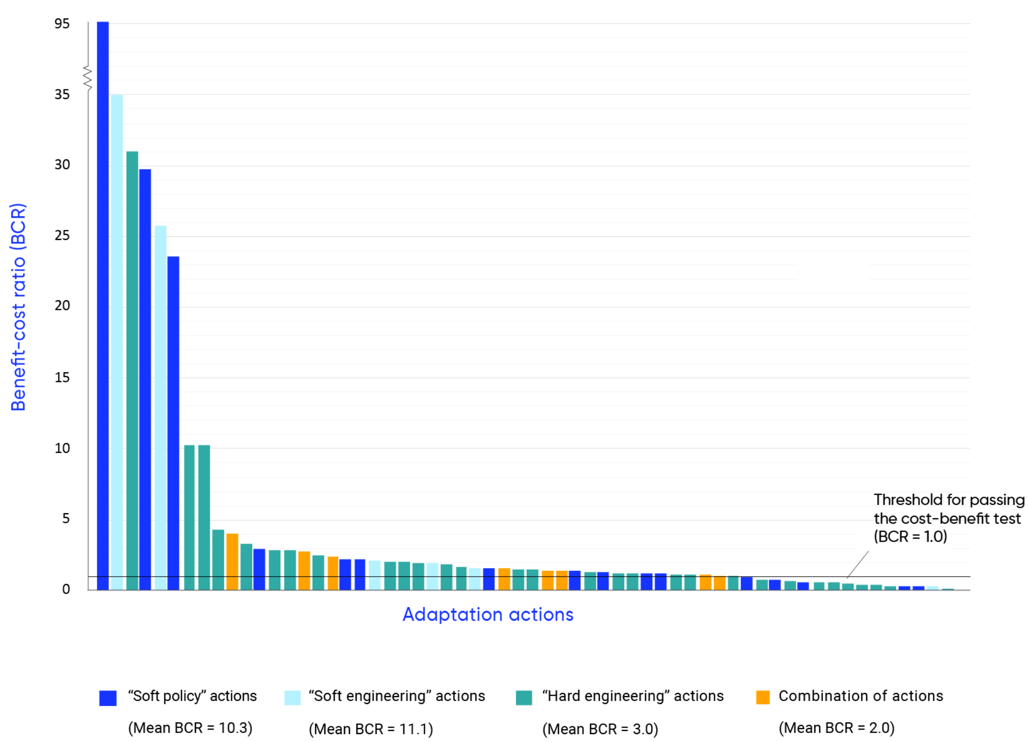

95
35
30
25
20
15
10
5
0
Benefit-cost ratio (BCR)
Threshold for passing the cost-benefit test (BCR = 1.0)
Adaptation actions
"Soft policy" actions (Mean BCR = 10.3)
"Soft engineering" actions (Mean BCR = 11.1)
"Hard engineering" actions (Mean BCR = 3.0)
Combination of actions (Mean BCR = 2.0)

Figure 6.16: The figure shows estimated benefit-cost ratios (BCR)—present-value benefits divided by present-value costs—for 60 adaptation actions in Canada (*see* Appendix 6.4). Of the actions considered, 75% have a BCR greater than one, indicating that the benefits exceed the costs incurred to generate those benefits (i.e., these would typically be considered as justifiable investments on economic efficiency grounds). The unweighted average BCR across the 60 actions is 5.6, although the unweighted median BCR is 1.5. a) shows the benefit-cost ratios of different types of adaptation actions from the sample, differentiated by climate-sensitive sector, and b) shows the benefit-cost ratios of these actions, differentiated by category of adaptation action: “soft policy” actions (e.g., planned retreat, enhanced pest control, flexible scheduling); “soft engineering” actions (e.g., beach nourishment, green roofs); “hard engineering” actions (e.g., dykes, weirs, sea walls); and “combination” actions. Data source: *see* Appendix 6.4.

6.7.3 Residual damages

It is evident from the NRTEE (2011) studies in Appendix 6.4 that, even with adaptation actions in place, residual costs from damage due to climate change remain. For instance, the cost of adopting a portfolio of adaptation actions to address the impacts of climate change on timber supply is $2.3–3.6 billion (in present value terms, at a 3% constant discount rate over the period 2010–2080) and reduces economic losses by $19.9–137.9 billion, but residual losses of $4.6–37.1 billion remain. The total costs of climate change in this case are therefore $6.9–40.7 billion. While not explicitly reported by the other studies listed in Appendix 6.4, a quick comparison of the results in Appendix 6.1 and Appendix 6.2 with those in Appendix 6.4 reveals the presence of residual damage costs in most cases, suggesting potential—though undefined—limits to what adaptation can achieve (*see* Section 6.8.1). The presence of residual costs does not indicate that an action is poorly designed or that an insufficient level of adaptation was implemented; it may simply indicate that aiming for zero residual damages is not feasible or that its costs would exceed the dollar value of avoided damages.

6.8 There are economic barriers and limits to adaptation

There is a range of ecological, technological, economic and institutional barriers to adaptation, which limit the potential to reduce negative climate change impacts and benefit from new opportunities. Government can play an important role in addressing these barriers, although an economically efficient level of adaptation will likely involve some residual costs.

In addition to financial constraints, various market, behavioural and policy barriers are contributing to an adaptation gap—the difference between the level of adaptation required to offset all negative climate change impacts or to benefit from all new opportunities. This is further complicated by ecological and technological limits to adaptation. Government intervention can play a strong role in addressing these barriers and incentivizing adaptation by other actors. Some adaptation actions and public policies designed to support *adaptation cannot be justified on economic grounds (i.e., with social costs that exceed social benefits) or will simply be too costly relative to available resources. Consequently, the level of adaptation that is achievable, even with government intervention, will generally not overcome all consequences of climate change. Residual damages will likely be part of any economically efficient adaptation strategy.*

6.8.1 Introduction

Both theory and evidence indicate that adaptation cannot cancel out all negative climate change impacts, nor can it capture all positive impacts (Chambwera et al., 2014; Dow et al., 2013). Earlier sections in this chapter highlight potential instances of insufficient or ineffective adaptation (e.g., the current adaptation deficit with respect to extreme weather events in Canada) (*see* Section 6.4.2). This section examines barriers and limits to adaptation from an economic perspective. A barrier refers to any type of challenge, obstacle or constraint that can impede or stop the adoption of certain adaptation actions by businesses or households, but that is surmountable with concerted effort; a limit is a constraint that cannot be overcome without incurring unreasonable costs or taking unreasonable action (Eisenack et al., 2014; Productivity Commission, 2012).

6.8.2 Barriers and limits to adaptation from an economic perspective

From an economic perspective, private actors such as businesses and households are expected to undertake a significant amount of adaptation as they modify decisions and behaviours in response to climate signals to maximize their profit or welfare (Mendelsohn, 2012). Such behavioural reactions to climate stimuli form the premise underlying what is referred to as autonomous adaptation (Fankhauser, 2017). For example, people adjust their vacation destinations or travel dates in response to climate (Hamilton et al., 2005), and farmers adjust crops or use different harvest or seeding dates in response to changing precipitation patterns (Food and Agriculture Organization, 2007).

However, there is evidence that autonomous adaptation by businesses and individuals is not always adequate or efficient (Eisenack et al., 2014; Klein et al., 2014; Porter et al., 2014; de Bruin et al., 2011; Agrawala et al., 2010). There are multiple barriers and limits to private adaptation (Biesbroek et al., 2013), which means that only a subset of adaptation needs may be met in practice (*see* Figure 6.17). Limits can be technological (e.g., snow-making equipment may not be able to sustain adequate snow cover at lower altitude ski resorts as the climate warms), ecological (i.e., ecosystems and species may be unable to adapt at higher rates of warming), economic (i.e., the level of adaptation that is justified on economic grounds once the lifecycle costs of actions have been considered, in relation to the projected benefits), and institutional (e.g., available funding and capacity) (Chambwera et al., 2014). The gap between the level of adaptation required to cancel out all negative impacts (or capture benefits from all opportunities) and the maximum potential for adaptation after taking into account technological and ecological limits is referred to as the "unavoidable impacts" (Chambwera et al., 2014). However, not all actions for overcoming avoidable impacts will pass a basic cost-benefit test, which is indicative of the economic potential for adaptation. The lifecycle costs of some adaptation actions will exceed the economic costs averted, indicating that alternative investments offer better value for money.

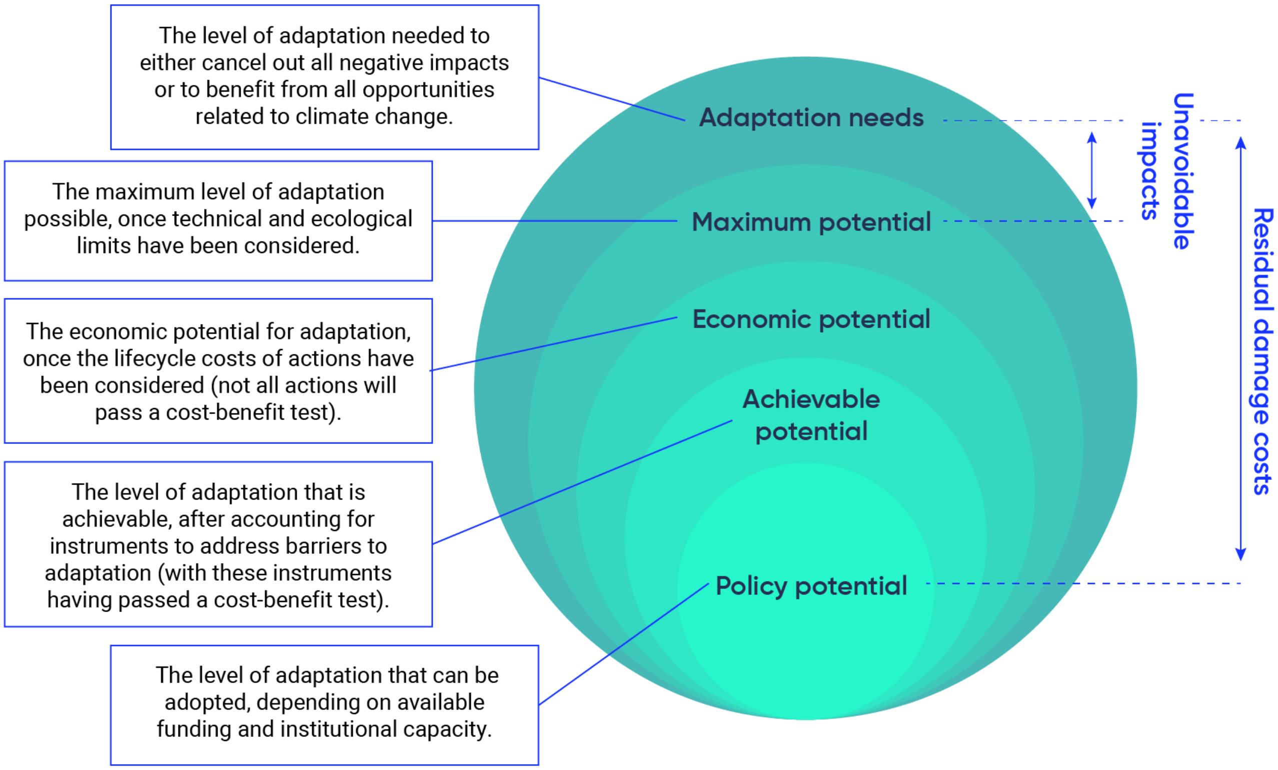


Figure 6.17: Economic barriers and limits to the maximum potential for adaptation. Source: Adapted from Chambwera et al., 2014; US Environmental Protection Agency, 2007.

6.8.2.1 Market failures

Simply because an adaptation action passes a cost-benefit test in theory does not necessarily mean that it will be adopted in practice. The economics literature is rife with a long list of barriers that can hamper the ability of individuals and businesses to allocate resources to welfare-improving adaptation actions (Klein et al., 2014). Markets may fail to provide decision makers with appropriate information about all of the costs and benefits of adaptation, leading to inefficient levels of investment in adaptation. This may happen because the required information is inadequate or not equally available to all parties in a decision, and may also be due to the presence of externalities, public goods and misaligned incentives, where the benefits of adaptation do not accrue to the individual or entity paying for it (*see* Box 6.2; Productivity Commission, 2012; Braeuninger et al., 2011; Ekstrom et al., 2011; Cimato and Mullan, 2010; Moser and Ekstrom, 2010; Stern, 2006).

Box 6.2: Market failures and adaptation

Market failures are imperfections in market mechanisms that lead to an inefficient allocation of resources. In the context of adaptation, market failures can lead to less efficient or effective adaptation, missed opportunities and higher costs (Moser and Ekstrom, 2010). There are several reasons why market mechanisms fail:

Information failures

Private actors may not have access to perfect information to inform their decisions. They may lack information on current and future climate risks, and the range of adaptation actions that are at their disposal; they may also be unaware of the costs and benefits of these actions. This makes it difficult to make efficient decisions. There may also be situations where information is known to some actors (e.g., homeowners), but not to others (e.g., potential buyers and insurers). This can lead to opportunistic behaviour by the individuals who hold superior information. For instance, a homeowner may underinvest in adaptation in the belief that someone else (insurers or government) will deal with any impacts. In other situations—like the management of property or assets—misaligned incentives might be an issue, whereby the costs of adaptation are borne by certain actors (e.g., property owners), while the benefits accrue to others (e.g., tenants). A property owner has little incentive to invest in water efficiency measures, for instance, when tenants pay the water bills.

Public goods

Markets have difficulty in supplying public goods because of the “free-rider” problem. This problem arises when individuals can benefit from the presence of a good or service without having to contribute to its provision. Examples of public goods in the case of adaptation include large-scale community flood protection, climate models and information about climate change impacts, public health and safety, and emergency preparedness. These goods will be underprovided or not provided at all by private markets. One reason for this is the difficulty of excluding nonpayers from enjoying the benefits of the good (such as coastal protection infrastructure), making it challenging to turn a profit. Furthermore, for some goods and services that are affected by climate change (such as ecosystems), markets do not exist. In these cases, there is no market mechanism for allocating resources to adaptation.

Externalities

Externalities occur when adaptation actions by some individuals result in unintended consequences (positive or negative) for other individuals, without payment or compensation taking place between the parties; this is because the unintended consequences are not captured by market prices. For example, increased use of air conditioning by some individuals in response to rising temperature extremes might result in increased GHG emissions, poorer air quality and adverse health effects for other individuals, though the associated health and welfare costs are typically not borne by those who are using air conditioners.

6.8.2.2 Behavioural failures

Even when markets send private actors the right signals, these actors do not necessarily make choices in their best interests or those of society at large, due to several behavioural anomalies and biases. The type, complexity and volume of information available, and the way in which it is communicated and by whom, all have a significant impact on the likelihood that people will read, understand and use it efficiently. Cognitive capacity, for instance, is known to affect our ability to make efficient adaptation decisions involving complex, probabilistic information (Grothmann and Patt, 2005). Other potential behavioural anomalies and biases manifest as decision inertia, procrastination and high discount rates (e.g., Boyd et al, 2015). As a result, individuals are observed to make seemingly irrational choices that deviate from what classical economics would predict (i.e., to maximize net benefits or welfare). Such irrational aspects of decision making are often referred to as behavioural failures.

6.8.2.3 Policy failures

Policy failures can also create barriers to the adoption of an economically efficient level of adaptation (Her Majesty's Government, 2013; Cimato and Mullan, 2010). These failures arise when regulation distorts market transactions, thus incentivizing private actors to under- or over-invest in adaptation. For example, government transfers for hard flood protection measures and disaster aid provide incentives that fuel a self-reinforcing cycle of continued growth in coastal areas that are prone to flooding, even though retreat or abandonment represents the welfare-maximizing course of action (Kousky, 2014; Filatova 2013; Filatova et al., 2011). Taxes on insurance products and property transactions are another example (Boyd et al., 2015). Policy failures can also occur in the presence of conflicting or competing policy objectives, or when there is a lack of clarity around objectives.

6.8.3 Role for governments

The presence of market, behavioural and policy failures means that the economic potential for adaptation is not fully realized. This creates a key role for government (Fankhauser, 2017):

- Firstly, to remove policy distortions that impede economically efficient adaptation choices by private actors: for example, to reform (e.g., reduce, restructure or eliminate) the subsidies that fuel the self-reinforcing cycle of continued growth in coastal or riverfront areas that are prone to flooding (Boyd et al., 2015).
- Secondly, to use regulatory and economic instruments to overcome market and behavioural failures, and to provide incentives for efficient private adaptation (e.g., Boyd et al., 2015; Hotte and Nelson, 2015). Regarding the use of economic instruments to incentivize adaptation, it is important for the design of these instruments to account for common behavioural failures that have the potential to undermine their effectiveness (Boyd et al. 2015).

- Thirdly, to provide public goods and services dedicated to adaptation, like the production and dissemination of climate information, spending on research and monitoring programs, investment in large-scale flood protection, early warning systems for communities, improvements to emergency planning and preparedness, and the development of policies to enhance the resilience of ecosystems.

However, not all forms of government intervention will make sense from an economic perspective. It is also necessary to demonstrate that the benefits arising from such interventions exceed the costs of implementation for private actors and government (Productivity Commission, 2012). Only a certain level of adaptation is achievable after accounting for the effectiveness of regulatory and economic instruments to redress barriers to efficient adaptation, with these instruments themselves having passed a cost-benefit test (*see* Figure 6.11).

Some individuals, businesses or communities may be unable to afford or finance the required investment in planned adaptation actions, even though they know it is in their best interest to do so (Lecocq and Shalizi, 2007).[9] Another role for government is to aid vulnerable and disadvantaged groups and communities that do not have access to the necessary resources to adapt sufficiently (Fankhauser, 2017). At the same time, governments too will face financial and capacity constraints, and must allocate resources among competing needs. When an economically efficient level of adaptation is achieved after allowing for technical, social and ecological constraints, residual damages may well occur. The fact that some level of residual damages may be unavoidable gives rise to a range of important ethical and social justice issues that are at the core of the "loss and damage" discourse at the international level—referring to unavoidable impacts beyond the limits of adaptation (van der Geest and Warner, 2015). While a discussion of these issues is outside the scope of this chapter (*see* Wallimann-Helmer et al., 2019 for an overview of the main ethical and justice challenges), government may also have a role in defining what is an acceptable level of residual damage and how best to reconcile the welfare effects of these unavoidable impacts.

6.9 Moving forward

Decision makers are increasingly demanding information on the current breadth and depth of evidence available for characterizing the costs of climate change for Canada, as well as the net value of different adaptation actions, for the purpose of informing the business case for action. There is an increase both in the volume and quality of evidence on the costs of climate change, and on the costs and benefits of adaptation, reflecting the growing importance of economic information for decision makers. However, there are also many knowledge gaps, which points to a rich new research agenda.

9 Market failures can also occur in financial systems (e.g., if a potential borrower has better information about their ability to repay a loan than the lender) and can limit how much, if anything, an individual or business can borrow, or can lead to unfavourable financing terms and interest rates.

6.9.1 Costs of inaction

There is much that is yet to be known about the costs of climate change for Canada, both in aggregate and for specific sectors, regions, communities and vulnerable populations. Future projections of the total economic consequences of climate change for Canada are highly uncertain. Some simplified, highly aggregate modelling exercises project net gains for Canada's economy, while others project net losses. Further study is needed to resolve uncertainty around the aggregate cost of climate change for Canada.

Adaptation decisions are largely made at the local or provincial level, where the current state of knowledge regarding the cost of inaction is highly fragmented. There are large knowledge gaps when it comes to the Prairie provinces, the Northwest Territories, the Yukon and Nunavut, the Interior of British Columbia, Ontario, as well as First Nations, Inuit and Métis peoples. Furthermore, high-quality estimates of economic consequences exist for only a few Canadian cities. Given that most adaptation decision making takes place at the local level, a priority for future research should be not only to resolve uncertainty around the total economic consequences for Canada in aggregate, but to improve the geographical coverage and scope of damage estimates for municipalities, as well as the level of disaggregation by sectors, assets and services, and climate hazards. This implies the need for a bottom-up, multi-sector approach that addresses several cross-cutting gaps in the current literature. Recommendations for new economic studies include the following:

Studies considering a broader range of climate hazards: Most of the available national-level aggregate projections (and most regional projections) are focused on slow-onset climate impacts (i.e., gradual changes in temperature and precipitation, and select biophysical impacts that result from these changes). Future investigations of economic consequences would benefit from increased attention on extreme events and catastrophes (i.e., low-probability and high-consequence events).

Studies considering a broader range of climate-sensitive sectors: Some sectors are better represented in the current economic literature than others. A range of estimates are available for coastal zones, agriculture and forestry. For other sectors—namely, tourism, labour, water resources and public health—only a few incomplete estimates are available. There are also major gaps in our understanding of the economic consequences of climate change for public health. Other sectors are not yet represented in the literature, such as ecosystems, fisheries, energy infrastructure (including oil and gas), transportation infrastructure (including rail, air and ports), water quality and security (e.g., crime, migration, conflict).

Studies considering a broader range of economic impacts: A comprehensive assessment of economic consequences would capture both market and non-market impacts. An important consequence of climate change for welfare is the loss of goods and services that are not traded in markets and therefore cannot be valued using market prices or captured by CGE models. Examples of broader economic impacts worthy of study include species loss, pain and discomfort, loss of cultural heritage, conflict and forced migration. These welfare losses can be sizeable, even though they are largely omitted from current estimates. Research is needed to ensure that they are better represented in future estimates of economic impacts.

Studies considering inter-sectoral impacts: There is a broad range of potentially important inter-sectoral impacts that are not well captured, especially within a bottom-up, multi-sector approach. For example, water is used to produce electricity (e.g., for thermal cooling), and electricity is used to supply water (e.g., to operate pump stations). These linkages are typically omitted from estimates. Some non-biophysical interactions occur through market mechanisms and can be captured using CGE models, for instance. Other interactions do not function in this manner, such as when damage to ecosystems amplifies other impacts. Research is needed to understand which inter-sectoral linkages are economically significant at a local or regional level, and should therefore be captured in the next generation of estimates.

Studies considering socioeconomic developments: An important conclusion from the current literature concerns the importance of future socioeconomic change (e.g., growth in populations, assets and wealth) as a key driver of the absolute magnitude of projected economic costs. Despite the demonstrable role of such change as a determinant of the cost of inaction, socioeconomic futures are either incompletely addressed or not addressed at all in many current studies.

6.9.2 Costs and benefits of adaptation

Knowledge relating to the appraisal of adaptation costs and benefits in Canada is currently restricted in scope to a few climate-sensitive sectors, which in turn means that only a narrow range of adaptations to a limited set of climate impacts in specific regions has been considered to date. Also, existing studies are almost exclusively focused on the public sector. Consequently, despite the promising results from existing studies (*see* Section 6.7.1), it is not possible to make widespread generalizations about the economic attractiveness of adaptation actions in all contexts. There is a lot to learn about the costs and benefits of the full range of adaptation that is likely needed to manage the impacts of climate change regarding tolerable levels. Research is needed to understand more about the economic efficiency of capacity building actions and public policy interventions to overcome barriers to adaptation. This includes understanding how lessons from behavioural economics can be used to improve the design and effectiveness of policies to provide incentive for implementing desirable levels of private adaptation. At the same time, a better understanding of current public policies that promote maladaptation is needed; removing prevailing policy failures is crucial if interventions to incent adaptation are to be effective.

While theory favours short-lived, flexible and relatively inexpensive "soft" adaptation measures over long-lived, capital-intensive, "hard" adaptation measures in the face of deep uncertainties, it has yet to be demonstrated in Canada through practical applications which adaptations have the greatest merits, and under what circumstances. Case studies are needed to better understand the economic merits of sequencing adaptation decisions over time under multiple futures, rather than making a single, seemingly optimal decision now. All of the current "proof of principle" examples are international.

Current economic appraisals pay scant attention to distributional issues and to the political economy of adaptation (i.e., how adaptation decisions are made, taking into account political, cultural and economic factors). Adaptation, like any form of intervention, will typically have winners and losers, although none of the economic studies that have been formally reviewed considered the distribution of costs and benefits across actors. Since distributional impacts are a major talking point in local, provincial and national debates about climate policy, a sounder understanding of these impacts would aid in both the design of adaptation actions and in moving towards implementation.

Finally, awareness of the cost of climate change adaptation in Canada is only starting to develop, helped by two recent studies of the level of investment needed to adapt public infrastructure to climate change at the national level (Insurance Bureau of Canada and Federation of Canadian Municipalities, 2020) and in Quebec (AGECO Group, 2019). However, many knowledge gaps remain. For instance, there is no information on the aggregate level of investment needed to adapt other economic sectors for anticipated climate change impacts. Even regarding public infrastructure, there is poor understanding of adaptation investment needs for certain parts of the country (e.g., British Columbia and Nunavut) and for larger population centres. These knowledge gaps make it difficult to characterize the scale of the required adaptation effort, how it should be financed and—in conjunction with estimates of adaptation benefits—how available funds should be deployed.

6.9.3 Emerging issues

The framing of adaptation decision making is changing, with implications for adaptation economics. Whereas the predominant approach to navigating the assessment and planning stages of an adaptive risk management framework was historically based on a "science-first" (or "top-down") approach, there has been a recent shift in the economic literature towards a "policy-first" (or "bottom-up") analytical process, with a focus on early action (*see* Section 6.2.3).

This shift has significant implications for the economic analysis of adaptation actions and necessitates the development and application of alternative decision support tools. Where consideration of deep uncertainties over future impacts is important—and where decision makers are looking for flexible or robust options—new economic decision support tools like adaptation pathways, real options analysis, robust decision making and portfolio analysis are more appropriate for economic appraisal than conventional tools like cost-benefit analysis (*see* Section 6.2.5).

The greater importance placed on capacity building, behavioural interventions and the value of information under the "policy-first" approach also creates challenges for the monetization of costs and benefits, requiring different approaches to the quantification of physical impacts and their subsequent valuation. Increased consideration of the adaptation process also places greater emphasis on understanding barriers and economic limits to efficient adaptation (e.g., market, behavioural and policy failures), and on the costs and benefits of government interventions designed to overcome these barriers (*see* Section 6.8). Designing effective policy interventions requires an understanding of behavioural responses to different incentives. In short, economic decision support is itself adapting to meet the evolving needs of decision makers.

There is growing recognition that an efficient level of adaptation is being hampered by more than issues of affordability. A combination of market failures (e.g., lack of quality, accessible information on relevant risks and adaptation responses, or the presence of public goods or externalities), behavioural anomalies (e.g., cognitive capacity, inertia, high discount rates) and prevailing policy distortions (e.g., subsidies that ultimately promote maladaptation) limit the potential for adaptation (*see* Section 6.8). There is a greater role for government at all levels to do more than provide financial assistance and invest in public goods (such as climate information services). Other important steps to take include removing prevailing policy distortions, and designing and implementing regulations and economic instruments to overcome relevant market imperfections and behavioural failures. Equally important is the need for governments to reflect on what would be an acceptable level of residual damage and how best to address the welfare effects of unavoidable impacts, given the potential for significant ethical and social justice concerns.

Another talking point in the economic literature is the extent to which the economic consequences of climate change could be much higher than current projections suggest—not because of the limitations of emissions and climate change impact models, which omit important risks, but because of how economic models treat damages and growth. The issue is whether the level of economic output is either reduced by a climate shock or stress, but with the underlying rate of economic growth being unaffected, or whether climate change has a more persistent, cumulative impact on the growth rate itself. Until recently, most estimates of the cost of climate change were based on static losses of annual economic output. However, if climate change causes lasting damage to capital stock, land and the efficiency at which these factors and labour are turned into economic output, as some scholars suggest, then the annual growth rate will be affected in addition to the output level, leading to much deeper and longer-lasting impacts on economic output, due to the compounding effects of reduced growth. The debate remains unsettled in the literature.

6.10 Conclusion

This chapter assessed the state of knowledge and practice of climate change impacts and adaptation economics in Canada. Information on the economic consequences of climate change, as well as the costs and benefits of adaptation actions, are increasingly being demanded by a wide range of decision makers. Within an adaptive risk management framework, economic information can be used to raise awareness about the need to allocate resources to adaptation planning, as well as to inform the prioritization of current and future climate risks and vulnerabilities. Economic information can also be used to inform the selection and level of resources allocated to adaptation actions. Overall, the breadth, depth and quality of knowledge in Canada on this topic are increasing. There is much that we now know about the potential costs of climate change for certain regions, sectors and cities. A strong business case is also evident for adaptation investments in specific contexts. While the state of knowledge and practice is improving, it is clear that the evidence base is still highly fragmented and that important gaps in knowledge and coverage remain.

There is evidence of an adaptation deficit or gap in Canada, demonstrated by the fact that households, businesses and infrastructure, etc. are under-adapted to current climate conditions and variability. Not all of the rising losses can be explained by growing exposures, asset values and general price inflation, suggesting that climate change may be playing a role, potentially foreshadowing growing levels of losses that might be expected in the future with climate change anticipated to intensify. Do projections of future climate change costs for Canada support this conjecture? The short answer is yes. The bulk of the evidence suggests that climate change will impose increasing overall welfare losses on Canadians, though welfare gains are expected in some sectors and in some parts of the country.

Looking to the future, climate change is projected to impose substantial economic costs on individual sectors and regions. Under high-emissions scenarios without new adaptation actions, economic costs in some sectors and regions could amount to 100s of millions to 10s of billions of dollars annually by the 2050s, and higher still by the end of the century (NRTEE, 2011). Affected sectors and regions include forestry, coastal areas, public health, ski resorts, marine transport, hydroelectric generation, municipal water treatment and waterfront properties in the Great Lakes–St. Lawrence River system. Projections of economic consequences for agriculture vary—most studies project economic benefits from climate change impacts on crops, with the largest gains being in the Prairie provinces. The limitation is that these studies only consider changes under average conditions, and do not consider the negative impacts associated with changes in climate and weather extremes. For the few cities for which information is available, climate change is anticipated to have negative economic consequences.

The economic consequences of climate change for Canada can be assessed at a mix of different spatial scales (national, provincial/territorial, regional, municipal) and sectoral scales (single-sector or multi-sector). At each scale, cost assessments may also differ significantly in scope—in terms of the climate impacts considered (e.g., one or more slow-onset impacts or rapid-onset impacts), the types of costs measured (e.g., direct, indirect, macroeconomic, market, non-market) and time frames (e.g., short-term, medium-term, long-term). In general, existing studies of the economic impact of climate change have been very narrow in scope and sectoral coverage. Higher damage costs are projected by studies with wider scopes that considered extreme weather and climate events in addition to slow-onset climate change impacts, captured impacts on multiple sectors, included non-market impacts and measured impacts on the welfare of Canadians, as opposed to changes in GDP. If cost assessments adopted a more comprehensive scope, then the estimated costs of climate change for Canada would likely be significantly higher than the current studies suggest.

Economic appraisals of adaptation actions in Canada find that the benefits generally exceed the costs, though results are highly context-specific. Across a narrow sample of 60 appraisals of actions (largely in municipal settings) to reduce impacts from coastal flooding, low water levels in the Great Lakes–St. Lawrence River system, reduced timber supply, heat stress and poor air quality in Toronto, 75% of the actions passed a cost-benefit test. The median benefit-cost ratio was 5.6:1 (1.5:1)—each dollar spent on risk reduction generated, on average, $5.60 in benefits (*see* Section 6.7.2). Returns on investment in adaptation of these magnitudes are consistent with the international experience.

Several observations can be drawn from the available evidence. Firstly, among the sample of adaptation actions that were assessed, “soft” adaptation actions provided better value for money than did “hard” engineering actions, due primarily to lower investment costs and the propensity to provide greater co-benefits. A number of these actions are also characterized as nature based solutions, where action is taken to reinforce and protect existing ecosystems. Secondly, the economic performance of adaptation actions is highly site-specific and context-specific—the same action that passes a cost-benefit test at one location may fail at another location, and results are not generally transferable. Thirdly, adaptation does not typically cancel out all climate change costs—some residual damage costs persist. This latter point highlights potential ecological, technological and economic limits to adaptation. It also implies that even with an economically efficient level of adaptation, welfare levels might still be lower than they otherwise would be in the absence of climate change. The fact that some level of loss may be unavoidable presents a range of ethical and social justice challenges, requiring governments to define what is an acceptable level of residual damage and how best to reconcile the welfare effects of these unavoidable impacts.

Overall, the emerging business case for adaptation looks promising, although the evidence base is incomplete. There is still a lot to learn about the costs and benefits of adapting to current and future climate change in a broader range of sectors (including the private sector), about the broader range of risks, and the need to consider a broader set of actions, including regulatory and economic instruments. Little is known about the distribution of adaptation costs and benefits. All current studies reviewed in this chapter are prospective appraisals of largely hypothetical adaptation actions that could—in principle—be adopted. None of the findings are based on retrospective evaluations of implemented actions; thus, the findings are more representative of the theoretical "economic potential" for adaptation, as opposed to the more realistic "policy potential" (*see* Figure 6.11).

Providing projections of quantifiable financial costs and benefits is not enough given the diverse objectives, interests, knowledge and values that decision makers now bring to climate change adaptation decisions. There are many available economic tools that can support multi-metric appraisals, although only simple forms of traditional CBA have been applied to date. Firstly, there are approaches to capture distributional impacts, intergenerational equity issues, co-impacts and non-market impacts within traditional tools like CBA. Secondly, economics offers a set of new approaches that work with traditional tools like CBA to provide useful support for adaptation decision making under deep uncertainty, incorporating the time-phasing of actions over long time frames and the potential for learning. Each of the available tools has unique strengths and weaknesses depending on the adaptation decision context and the level of uncertainty. There is no "best" one-size-fits-all approach to the economic appraisal of adaptation actions.

The choice of economic decision support tool(s) might be case-specific, but the literature does identify several best practices that would characterize good economic analysis, in particular the following: covering a broad representation of specific climate and biophysical impacts—including both extreme rapid-onset and slow-onset impacts; considering projected socioeconomic developments; considering multiple "hard" and "soft" adaptation actions, including analysis of barriers to their effective adoption, and interventions to address these barriers; investigating both climate and non-climate sources of uncertainty, including consideration of the time phasing and sequencing of actions using new economic tools for decision making under uncertainty (e.g., adaptation pathways, real options analysis); analyzing lifecycle costs (including transaction costs) and benefits across the broadest practical scope of market and non-market impacts; and scrutinizing distributional impacts on vulnerable populations, disadvantaged groups and future generations.

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6.12 Appendices

Appendix 6.1: Summary of select national and regional studies of the economic consequences of climate change for specific climate-sensitive sectors in Canada

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Forestry				
NRTEE (2011) (national and provincial/ territorial)	Mean annual temperature change for Canada by 2050 under low (IPCC SRES B1; +3.4°C) and high (IPCC SRES A2; +3.6°C) climate change scenarios GDP growth for Canada by 2050 under slow-growth (+1.3% per annum) and rapid-growth (+3.0% pa) scenarios	Impacts on timber supply from forest fires, pests and diseases, and changes in forest productivity Changes in projected GDP relative to “no climate change” baseline (using the CGE model)	Range of annual GDP losses in undiscounted 2008 $ (and % change in GDP) by 2050 for Canada under a low climate change–slow growth scenario, and a high climate change–rapid growth scenario: $2.4–17.4 billion (-0.12% to -0.33%) Present-value total GDP losses[1] over 2010–2080 at a 3% discount rate: $25–176 billion	Range of annual GDP losses in undiscounted 2008 $ (and % change in GDP) by 2050 for specific provinces and territories under a low climate change–slow growth scenario, and a high climate change–rapid growth scenario: • AB: $0.2–1 billion (-0.06% to -0.14%) • Atlantic Canada: $0.1–0.5 billion (-0.07% to -0.21%) • BC: $0.5–3.1 billion (-0.18% to -0.44%) • MB, SK, NU, NWT and YT: $0.5–$3.3 billion (-0.33% to -0.85%) • ON: $1.0–7.4 billion (-0.11% to -0.31%) • QC: $0.3–2.1 billion (-0.08% to -0.23%)

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Ochuodho et al. (2012) (national and provincial/ territorial)	Low (IPCC SRES B1; +3.4°C) and high (IPCC SRES A2; +3.6°C) climate change scenarios (NRTEE, 2011) GDP growth for Canada as per NRTEE (2011) through 2080: • slow-growth = +1.3% per annum • rapid-growth = +3.0% per annum	Pessimistic (worst-case) and optimistic (best-case) impacts on timber supply from forest fires, pests and diseases, and changes in forest productivity Changes (relative to "no climate change" baseline) in projected sector output values, GDP and welfare (compensating variation) using the CGE model	Range in present-value total losses for Canada for the period 2010–2080 under the optimistic low climate change–slow growth scenario, and the pessimistic high climate change–rapid growth scenario (in 2008 $ at a 3% discount rate): • Sector output: $6–707 billion • GDP: $4–459 billion • Welfare: $3–296 billion	Range in present-value total losses for specific provinces and territories for the period 2010–2080 under the optimistic low climate change–slow growth scenario, and the pessimistic high climate change–rapid growth scenario (in 2008 $ at a 3% discount rate): • AB: $1–21 billion • Atlantic Canada: >$1–15 billion • BC: $3–66 billion • ON: -$1–+$209 billion • QC: -$3 billion–+$76 billion • Rest of Canada: $4–72 billion In some of the above cases, productivity gains offset losses from fires and pests.
Hope et al. (2015)[2] (national and provincial/ territorial, excluding the Atlantic Provinces, Nunavut and national parks)	Change in the 4-month sum (May–August) of the Climate Moisture Index (CMI) projected by four general circulation models (GCMs) under RCP2.6 and RCP8.5, relative to the 1961–1990 climate normal Static socioeconomic scenario (i.e., suppression costs are constant in real terms)	Changes in the area burned as a function of projected changes in the CMI Changes in fixed and variable fire suppression costs (relative to costs incurred in 1980–2009) as a function of projected changes in the area burned	Total average annual fire suppression costs[3] (in 2009 $) by the 2080s, relative to the period 1980–2009: • Under RCP2.6: $625 million (or +60%) • Under RCP8.5: $640 million (+119%)	The two most affected provinces in terms of % change in fire suppression costs by the 2080s, relative to the period 1980–2009: • Under RCP2.6: AB (+141%) and SK (+218%) • Under RCP8.5: AB (+195%) and SK (+265%)

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Corbett et al. (2015) (British Columbia)	No emissions scenario per se, but a projection of Annual Allowable Cut in BC with mountain pine beetle infestations (32% decline over 50 years) Projected economic growth of 33% for BC over the period 2009–2054	Impact of mountain pine beetle infestations on timber supply in BC Changes relative to baseline in projected welfare (compensating variation) and provincial macroeconomic indicators, using the CGE model	Not applicable	Present-value total losses for BC for the period 2009–2054 (in current $ at a 4% discount rate): • GDP: $57 billion (decline of 1.3% per annum) • Welfare: $90 billion

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Agriculture				
Weber and Hauer (2003) (national and provincial)	Single model run of the CGCMII model (Canadian Centre for Climate Modelling and Analysis) covering the period 1950–2070 (note: specific changes in temperature and precipitation were not provided) Ricardian model of agricultural land values estimated for the period 1995–1996 (baseline is static)	Impacts of monthly and quarterly projected temperature and precipitation anomalies (30-year average over 2021–2051) on static 1995–1996 agricultural land values and farmland returns using a Ricardian model, with fixed prices	Projected climate-induced gains in agricultural land values for Canada (average over entire country) in 1995 $ per hectare: $1,485 Equivalent to 16% increase in 1995 national agricultural GDP of $32 billion (assuming returns are annualized at a +4.7% discount rate)	Projected climate-induced gains in agricultural land values by province in 1995 $ per hectare (and % change in provincial agricultural GDP): • AB: $1,675 (+23%) • BC: $1,145 (+7%) • MB: $1,425 (+17%) • ON: $2,215 (+5%) • QC: $1,460 (+4%) • NB: $1,225 (+6%) • NL: $570 (+1%) • NS: $775 (+5%) • PEI: $800 (>0%) • SK: $1,555 (+38%)
Reinsborough (2003) (national)	Assumed a mean annual temperature increase of 2.8°C uniformly across Canada and mean annual precipitation increases of 8% (relative to the 1961–1990 norm) Ricardian model of farmland values estimated for the period 1995–1996 (baseline is static)	Impacts of uniform increase in temperature and precipitation (relative to the 1961–1990 norm) on static 1995–1996 farmland values, using a Ricardian model with fixed prices	Projected climate-induced gains in farmland values for Canada (total for entire country) in 1995 $: +$0.9–1.5 million Negligible compared with the 1995 national agricultural GDP of $32 billion	Not considered

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Ochuodho and Lantz (2015) (national and provincial/ territorial)	Emissions scenario based on changes in crop yields and agricultural land values for the period 2006–2051, derived from Weber and Hauer (2007) and Cline (2007) Baseline scenario of projected economic growth (without climate change) over the period 2006–2051	Impacts of climate change on crop yields Changes (under emissions scenario relative to baseline scenario) in projected welfare (compensating variation) and provincial/ territorial macroeconomic indicators estimated using multi-regional CGE model, including the USA and rest of the world	% change between the present value of total GDP for Canada over the period 2006–2051 and the baseline scenario, at a 4% discount rate: +1.7%	% change in present value of total provincial/ territorial GDP and welfare, respectively, over the period 2006–2051: • AB: +2.5%, +1.9% • BC: +6.3%, +5.6% • MB: +1.3%, -0.1% • NL: +2.5%, -0.1% • NS: +1.4%, +1.2% • NB: +1.5%, -0.4% • ON: +1.0%, -0.65 • QC: +0.5%, +0.2% • PEI: +0.8%, -1.1% • SK: +0.5%, -0.5% • NWT, NU and YT: +0.4%, -0.1%

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Zhai et al. (2009) (national)	Emissions scenario based on changes in crop yields, with and without carbon fertilization effects, derived from Cline (2007) for the period 2010–2080 Baseline scenario of global average projected GDP growth of +3.1% (2010–2050) and +2.5% (2050–2080)	Impacts of climate change on paddy rice, wheat, other grain and other crop yields Changes (under emissions scenario relative to baseline scenario) in projected GDP, welfare (equivalent variation) and agricultural sector output, estimated using CGE model of global economy	Impact of climate change on welfare and select macroeconomic indicators for Canada, in terms of % change between projected scenario in 2080 and baseline: • Welfare: +0.2% • GDP: -0.2% • Terms of trade: +0.8% • Sector output (crops): +22.1% • Sector output (livestock): -15.3% • Sector output (processed foods): -1.6%	Not applicable

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Amiraslany (2010) (Prairie provinces)	Assumed mean annual temperature increases (relative to 1961–1990 norm) over the Prairies of +1.05°C (2020), +2.19°C (2050) and +3.26°C (2080), and precipitation changes (in mm per day) of +0.016 (2020), +0.116 (2050) and +0.186 (2080) Ricardian model of farmland values estimated from 1991, 1996 and 2001 data (baseline is static)	Impacts of uniform increase in temperature and precipitation (relative to 1961–1990 norm) on static farmland values, using a Ricardian model The model also included impacts of projected changes in wheat and canola prices with climate change of +5% by 2020, +15% by 2050 and +25% by 2080	Not applicable	Average projected climate-induced change in farmland values across AB, MB and SK, including price and planted area change in 1996 $ per hectare (and % change): • 2020: +$145 (+15%) • 2050: +$385 (+40%) • 2080: +$505 (+50%) Decreases in land values are projected for areas of southeast Alberta in all future time periods

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Ayouqi and Vercammen (2014) (Prairie provinces)	Projected temperature and precipitation changes based on the IPCC SRES A2 emissions scenario (from CGCM model only): • Mean annual temperature: +1.3°C (2020s), +2.6°C (2050s) and +4.1°C (2080s) • Mean annual precipitation: +5% (2020s), +12% (2050s) and +17% (2080s) Ricardian model of farmland values estimated from 1991, 1996, 2001, 2006 and 2011 data (baseline is static)	Impacts of uniform increase in temperature and precipitation (relative to 1971–2000 norm) on static farmland values (using a Ricardian model) The model also included impacts of projected changes in wheat, canola, alfalfa, barley and cattle prices with climate change: +5% by 2020, +15% by 2050 and +25% by 2080	Not applicable	Average projected climate-induced change in farmland values, including price and planted area change, across AB, MB and SK (in 2002 $), depending on Ricardian model specification used: • 2020s: +$1.1–1.7 billion per annum • 2050s: +$1.9–2.7 billion per annum • 2080s: +$1.9–4.1 billion per annum $4.1 billion is equivalent to 35% of the Prairie’s agricultural GDP in 2011 ($11.7 billion in 2002 $)

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Coastal areas				
National Round Table on the Environment and the Economy (NRTEE) (2011) (national and provincial/ territorial)	Sea-level rise by 2050 under low (IPCC SRES B1; +28cm) and high (IPCC SRES A2; +29cm) climate change scenarios GDP growth for Canada by 2050 under slow-growth (+1.3% per annum) and rapid-growth (+3.0% per annum) scenarios	Impacts of permanent flooding from sea-level rise and temporary flooding from storm surges relative to “no climate change” baseline Market value of lost dwellings and direct repair-replacement costs of damaged property	Annual coastal flooding costs for Canada attributable to climate change by 2050 (in 2008 $): • Low climate change–slow growth scenario: $0.9 billion • High climate change–rapid growth scenario: $8.1 billion Present-value total flooding costs over the period 2011–2100 (at a 3% discount rate): $109–379 billion	Range of annual coastal flooding costs attributable to climate change by 2050 (in 2008 $) for specific provinces and territories, based on the two climate change scenarios: • BC: $840–7,645 million • MB: $0–2 million • QC: $5–55 million • NB: $10–225 million • NL: $7–80 million • NS: -$10 to -$110 million • NU: $20–165 million • PEI: $4–55 million In NS, homes are abandoned and not rebuilt (as in the baseline case), hence the cost savings

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Withey et al. (2016) (national and provincial/ territorial)	Impacts in terms of direct damages from sea-level rise and storm surge for the 2050s, under the IPCC SRES B1 and A2 climate change scenarios (NRTEE, 2011) Projected economic growth in seven coastal regions over the period of 2009–2054	Impacts in terms of direct damage of flooding on dwellings, and to agriculture and forest lands from sea-level rise and storm surge relative to baseline scenario, with damages under current climate conditions Changes (relative to baseline) in projected welfare (compensating variation) and provincial/ territorial macroeconomic indicators, using a CGE model	Present-value total losses for 2009–2054 for Canada under the IPCC SRES B1 and A2 scenarios, relative to cumulative losses under current climate conditions (in 2008 $ and at a 4% discount rate): • GDP: $10–70 billion • Welfare: >$1–25 billion	Present value total losses to provincial/territorial GDP under the same scenarios (in 2008 $, at a 4% discount rate): • BC: $8–60 billion • NB: >$1–2 billion • NL: -$1–2 billion • NS: $0–1 billion • PEI: $0– >$1 billion • QC: >$1–8 billion • NU, NWT and YT: >$1–3 billion

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Boyer-Villemaire et al., (2016); Circé et al., (2016a); Parnham et al., (2016) (Atlantic Canada and Quebec)	Sea-level rise scenario for 2015–2064 based on RCP8.5; the erosion scenario is based on linear extrapolation of historical erosion rates; and the flooding scenario is based on projected return periods for floods Static socioeconomic scenario (i.e., no growth) and no new adaptation actions	Direct impacts of sea-level rise, storm surge and coastal flooding, plus coastal erosion Direct costs from damage to infrastructure, buildings and land; direct losses from business interruption and traffic disruption; costs of response and recovery; and range of non-market impacts (e.g., loss of natural habitats, loss of cultural heritage, decline in recreational use, etc.)	Not applicable	Present-value total direct costs for 11 case study sites, encompassing 46 coastal segments in Quebec and Atlantic Canada (in 2012 $, at a 4% discount rate): $1.2 billion Range of present-value direct costs per coastal segment (across all 46 segments): $0–$705 million Median present-value direct costs across all 46 segments: $1 million
Wilson et al. (2012) (Tantramar region of southeast New Brunswick)	Storm surge flooding scenario with climate change from Daigle (2012) Static socioeconomic scenario (i.e., no growth) and no new adaptation actions	Impact of climate change on storm surge flooding Direct damage to residential, commercial, industrial and public buildings and contents; direct damage to vehicles; and direct losses in terms of agricultural output	Not applicable	Expected annual costs[4] (in 2000 $): • 2000: $1.5 million • 2025: $1.7 million • 2055: $2.2 million • 2085: $3.1 million Present-value total annual costs over the period 2000–2100 (in 2000 $, at a 4% discount rate): $60 million

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Health				
Larrivée et al. (2015) (Quebec)	For heat stress: median temperature extremes and frequencies from ensemble of CMIP5 simulations for RCP4.5 and RCP8.5 For other health outcomes considered: biophysical impacts informed by literature Static socioeconomic scenario (i.e., no growth), and no new adaptation actions	Morbidity and mortality health outcomes associated with heat stress, vector-borne disease (Lyme disease) and West Nile virus) and aeroallergens (pollen) Government health-related expenditures, payments for days lost due to illness, private medical costs Premature mortality valued using Value of Statistical Life (VSL) = $3.6 million	Not applicable	Total present-value costs for Quebec government over 2015–2064 (in 2012 $, discounted at 4%) (mean, 10th and 90th percentile): • Heat stress ($370 million, $245–515 million) • Lyme disease ($60 million, $40–95 million) • West Nile virus ($35 million, none) • Pollen ($360 million, $290–430 million) For society, the mean total present-value costs are (including cost of premature mortality): • Heat stress ($33 billion) • Lyme disease ($745 million) • West Nile virus ($835 million) • Pollen ($475 million)

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Water levels (low flow)				
Larrivée et al. (2016) (St. Lawrence River, Quebec)	Two hydrological scenarios for the St. Lawrence River between the Quebec-Ontario border and Trois-Rivières, QC for the period 2015–2064: 1) critical annual flows gradually reached by 2040s, recovering partially thereafter; 2) lower flows than reference in summer and autumn by 2020 Static socioeconomic scenario based on historical data (i.e., no growth) and no new adaptation actions	Impact of low water levels in the St. Lawrence River on maritime transport; municipal water treatment; ecological services and fishing; recreational boating and tourism; hydroelectric generation; and waterfront property values	Not applicable	Total present-value direct costs over the period 2015–2064 (in 2012 $, at a 4% discount rate): • Foregone transport capacity: $40–210 million • Foregone water sales: >$0.1 million • Foregone use value and earnings from fishing: $3,220 million • Foregone value of boating days: $65–75 million • Foregone hydroelectricity sales: $50–90 million • Reduction in value of waterfront properties: $70 million

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Dorling and Hanniman (2016) (Lake Michigan-Huron)	Projected average water level for the period 2041–2060 from the scenario for 2050 projected by the Canadian Centre for Climate Modelling and Analysis (CCCma 2050); values for other years over the period 2015–2064 based on linear interpolation Static socioeconomic scenario based on historical data (i.e., no growth) and no new adaptation actions	Impact of low water levels in Lake Michigan-Huron (projected levels relative to the annual average for the period 1918–2014) on commercial shipping and harbours; tourism and recreational water activities; hydroelectric generation; and waterfront property values	Not applicable	Total present-value direct costs over the period 2015–2064 (in 2012 $, at a 4% discount rate): • Additional harbour maintenance costs: $90 million • Lost shipping capacity: $1,840 million • Additional dredging costs and lost rental income: $7 million • Cost of replacing lost hydroelectric generation: $6,200 million • Reduction in value of waterfront properties: $535 million
Millerd (2005) (Great Lakes–St. Lawrence River system)	Simulation of water depths in Great Lakes–St. Lawrence River system from three 2 x CO_2 scenarios (from the Canadian Centre for Climate Modelling and Analysis); projected water levels compared with normal average monthly water levels over the period 1900–1989 Static baseline: freight shipping data for 2001	Impact of low water levels in Great Lakes–St. Lawrence River system (projected levels relative to annual average for the period 1918–2014) on commercial shipping (bulk commodities, loose goods, petroleum products) Total cost of origin-destination voyage (loading, unloading and operating costs)	Not applicable	Increase in annual shipping costs (in 2001 $) with climate change (relative to 1900–1989 annual average): $20–75 million (or +8–29%), depending on how quickly the CO_2 concentrations double

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Mining				
Perrin et al. (2015) (Tibbitt to Contwoyto Winter Road, Northwest Territories)	Projections for specific climate variables of interest (i.e., freezing degree days and melting degree days) under RCP8.5 for the 2020s and 2050s (compared with the 1981–2010 norm) Static baseline: average road use (demand) for 2002–2012	Impact of climate-induced change on length of operating season (e.g., late opening, early closure, no opening) for the Tibbitt to Contwoyto Winter Road (TCWR), a mine access road built mainly over frozen lakes in NWT Direct cost of alternative transportation modes and direct production losses at applicable mines	Not applicable	Average annual total direct costs (price basis not specified): $215 million (of which $150 million are production losses and $65 million are costs related to modal shift), with 60% probability that costs could exceed the average

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Winter recreation – resort skiing				
DaSilva et al. (2019) (Mont Orford, Mont Sutton and Bromont Montagne in Quebec)	Mean value (and 10–90th percentiles) of relevant climate variables from 10 emissions scenarios covering all four RCPs for the period 2020–2050 Projected visitation at each resort (Mont Orford, Mont Sutton, Bromont Montagne) over the period 2020–2021 to 2049–2050, spanning 30 seasons (demand equations were estimated, including variables for weather and snow conditions)	Impact of climate change on beginning and length of ski season, skiable area and snow conditions for the three ski resorts in 2050, relative to 2020 Direct operating costs (e.g., power, maintenance, salaries, etc.) and direct changes in revenue from change in skier visitation (day and season passes, catering, etc.)	Not applicable	Change in aggregate direct revenues for all three resorts for the period 2045–2049 relative to 2020–2024 (in 2015 $): -$2.1 million (-6.4%) Change in aggregate direct operating costs: -$1 million (-3.4%) Change in aggregate direct net income: -$1.1 million (-29.2%)

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES	
			NATIONAL	*REGIONAL*
Butsic et al. (2011) (Whistler and Fernie, British Columbia)	Projections of snowfall equivalent to total precipitation (or "snowfall intensity") were constructed from (ensemble average) temperature and precipitation projections for the 2050s using the IPCC SRES A2 scenario (vs. the 1971–2000 norm) Static baseline: Hedonic property price model estimated using housing transaction data from the period 1980–2006	Impact of climate-induced change in "snowfall intensity" (5-year moving average) by the 2050s on house prices in Whistler, BC and Fernie, BC	Not applicable	Reduction in house prices near ski resorts in BC (% change relative to the 1980–2006 average): • Whistler: -3.2% for every 1% projected decrease in snowfall intensity • Fernie: -1.1% for every 1% projected decrease in snowfall intensity Snowfall intensity projections and total $ reductions in house values were not provided for BC resorts, only for USA resorts

[1] "Present-value total losses" is the discounted sum of the costs incurred each year between, in this instance, 2010 and 2080. See Section 6.6.3.2 and Appendix 6.3 on the rationale for discounting costs and for the choice of discount rate.

[2] The projected increases to wildfire suppression costs estimated by this study could be interpreted as reactive adaptation expenditures. There is a real opportunity cost associated with such additional expenditures, which would not be incurred in the absence of climate change. Hence, this study is included in the table.

[3] Average annual costs or losses are the average change per year over a defined period (e.g., 2071–2100).

[4] Use of the term "expected" means that the estimated average annual costs are probability-weighted.

Note: The estimated economic consequences of climate change in this table assume no new planned adaptation, relative to the baseline.

Appendix 6.2: Summary of select studies of the economic consequences of climate change for Canadian municipalities

STUDY	MUNICIPALITY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES
National Round Table on the Environment and the Economy (NRTEE) (2011)	Toronto, ON; Vancouver, BC; Calgary, AB; and Montreal, QC	Mean annual temperature change for Canada by 2075 under low (IPCC SRES B1; +4.3°C) and high (IPCC SRES A2; +5.3°C) climate change scenarios GDP growth for Canada under two scenarios: slow-growth (+1.3% per annum) and rapid-growth (+3.0% per annum)	Health outcomes associated with warmer summers (heat-related premature death) and poorer air quality (illness and premature death) Healthcare expenditures, welfare losses Premature mortality valued using Value of a Statistical Life: $6.1 million per death	Present-value total cost[1] of premature mortality attributable to heat and air quality impacts over the period 2010–2100 under the low climate change–slow growth scenario, and the high climate change–rapid growth scenario (in 2008 $, at a 3% discount rate): • Calgary: $11–17 billion • Montreal: $52–77 billion • Toronto: $65–96 billion • Vancouver: $36–48 billion Present-value total healthcare expenditures under the same scenarios described above (in 2008 $, at a 3% discount rate): • Calgary: $16–54 billion • Montreal: $54–213 billion • Toronto: $72–285 billion • Vancouver: $46–140 billion

STUDY	MUNICIPALITY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES
Thistlethwaite et al. (2018)	Halifax Regional Municipality, NS	Projected 24-hour precipitation intensity under RCP2.6 and RCP8.5 for the periods 2015–2045, 2035-2065 and 2065–2095, relative to 1955–2009 (historical conditions) Static baseline: 54,000 residential single dwellings in Halifax Regional Municipality	Impacts of rainfall-driven riverine flooding of residential property Insured losses (direct repair-replacement costs of damaged property and contents)	Average annual insured losses[2] under current climate conditions: $543,000 Average annual insured losses with climate change under RCP8.5: • By 2050: $1.3 million (+137%) • By 2100: $2.2 million (+300%)
Boyd (2018)	Edmonton, AB	Baseline scenario for 2018: annual probability of 17 extreme events (at a given intensity level) and degree days based on 1981–2010 data Projections of changes in extreme event probabilities (constant intensity) and degree days for 2050s and 2080s under RCP8.5 Baseline socioeconomic conditions defined by 2018 data Projected socioeconomic scenario for 2050s and 2080s; driven by population and housing forecasts, city growth studies, price forecasts, and relationships estimated from historic data	Market and non-market impacts of changes in the probability of climate-related extreme events and changes in heating and cooling degree days under a high-emissions scenario relative to the baseline scenario for 2018 Direct damages (repair-replacement costs) to residential, commercial and industrial buildings, home contents, business inventories, range of infrastructure and the natural environment; direct impacts to health & safety; direct losses from business interruption; and indirect and induced losses resulting from direct market impacts (estimated using city-level input-output multipliers)	Expected annual average net social costs[3] (in 2016 $, undiscounted) attributable to the impact of climate change on extreme events and heating and cooling demand in: • 2055: +$4.7 billion • 2085: +$10.3 billion Expected annual average net GDP costs in: • 2055: +$1.6 billion (1.6% of projected GDP) • 2085: +$3.5 billion (1.9% of projected GDP)

STUDY	MUNICIPALITY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES
Insurance Bureau of Canada (2015)	Halifax, NS; Mississauga, ON	Baseline scenario for 2015: intensity and return period of storm surge flooding and extreme wind events (Halifax Regional Municipality), and flooding from storm water and freezing rain events (Mississauga) based on historic data for the last 20–50 years Projections of extreme events for 2020 and 2040 under “moderate” (RCP4.5 or IPCC SRES B1 or B2) and “high” (RCP8.5 or IPCC SRES A2) emissions scenarios (from various sources) Baseline socioeconomic conditions defined by 2015 data Projected socioeconomic scenario for 2020 and 2040; driven by population forecasts and land-use plans, and by historic GDP growth trends	Market-based impacts of climate-related extreme events under moderate and high-emissions scenarios relative to baseline scenario Direct damages (repair-replacement costs) to residential, commercial and industrial buildings, home contents, power lines, plus direct losses from business interruption; and indirect and induced losses resulting from direct impacts (estimated using city-level input-output multipliers)	Cumulative expected GDP costs[4] attributable to climate change over the period 2015–2040 for moderate and high-emissions scenarios (in 2013 $, undiscounted) for Halifax Regional Municipality: • Storm surge flooding: $25–35 million • Extreme winds: $65–140 million Cumulative expected GDP costs attributable to climate change over the period 2015–2040 for the same scenarios as described above (in 2013 $, undiscounted) for Mississauga: • Storm water flooding: $30–70 million • Freezing rain: $28–31 million

STUDY	MUNICIPALITY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	ECONOMIC CONSEQUENCES
Lantz et al. (2012)	Fredericton, NB	Best-case and worst-case flooding return frequency scenarios constructed from downscaled General Circulation Models results (for 2020s, 2050s and 2080s) and projections of sea-level rise, which affects peak flood heights Projected population growth scenario over the next 50 years (low: -0.6%; high: +23%)	Impacts of freshwater flooding along the Saint John River in Fredericton Direct market costs to government (e.g., emergency services, clean-up and restoration, temporary lodging); business (e.g., property and inventory damage, additional operating costs); and households (e.g., property and content damage, temporary displacement costs, lost work time) Non-market costs for households (e.g., transport disruption, mental health, lost leisure time) collected via a survey using the contingent valuation method (minimum “willingness-to-accept” compensation)	Expected annual average direct costs due to climate change (price basis unknown): • Worst-case flooding return frequency and high population scenario: $13.2 million (of which $7.9 million are market costs and $5.3 million are non-market costs) • Worst-case flooding return frequency and low population scenario: $5.3 million (of which $4 million are market costs and $1.3 million are non-market costs) • Best climate and low population scenario: -$0.12 million (of which -$0.09 million are market costs and -$0.03 million are non-market costs • Best climate and high population scenario: -$0.32 million (of which -$0.18 million are market costs and -$0.14 million are non-market costs

[1] Present-value total cost is the discounted sum of costs incurred each year between 2010 and 2100. See Section 6.6.3.2 and Appendix 6.3 on the rationale for discounting costs and for the choice of discount rate.

[2] Average annual loss (or cost) is the average loss (or cost) per year over a defined period (e.g., 2050–2100).

[3] Use of the term “expected” means that the estimated average annual costs are probability weighted.

[4] Cumulative cost in this case means the undiscounted sum of costs incurred each year between 2015 and 2040.

Appendix 6.3: What is discounting?

The value attached today to receiving one dollar a year from now is expressed as:

$$1/(1+d)$$

Where d is the discount rate. If d were 0.05 (5%), the value of a dollar in one year's time would be 95 cents today. If the discount rate is constant, and one wants to know the value of one dollar two years from now, the 95 cents would decline by another 5% in the second year and be worth 91 cents today. The mathematical expression for that could be written as:

$$1/(1+0.05)^2 = 0.91 \times \$1 = \$0.91$$

Extending this over several years would result in a value that declines geometrically.

Hence, if an individual were to invest one dollar today, they would need to obtain a benefit of at least $1.05 in one year's time to consider the investment worthwhile. Likewise, the benefit required in two years would be $\$1.05^2 = \$1.05 \times \$1.05 = \$1.103$. In T years the amount required to make the investment worthwhile would need to be $(1+d)^T$.

In practice, the benefits of an adaptation investment likely accrue over several years, in which case the comparison must be made between the investment now and the sum of these benefits over future years, each discounted from the year in which it occurs. This sum is referred to as the present value (PV) and is written as:

$$PV = \sum_{t=1}^{T} \frac{B_t}{(1+d)^t}$$

Where B_t is the adaptation benefit in year t in monetary terms.

Appendix 6.4: Summary of select economic appraisals of adaptation actions in Canada using a cost-benefit analysis tool

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
		Forestry		
National Round Table on the Environment and the Economy (NRTEE) (2011) (national and by province)	Impacts on timber supply from forest fires, pests and diseases; changes in forest productivity	1) Enhance forest fire prevention, control and suppression 2) Enhance pest control 3) Plant tree species suitable for the future climate Aggregate adaptation costs for all three actions (present value for the period 2010–2080, in 2008 $): • Low climate change scenario: $2.3 billion • High climate change scenario: $3.6 billion	Present-value for 70 years (2010–2080) Constant discount rate: 3% per annum In 2008 $ (benefits of adaptation measured a change in welfare—compensating variation)	Combined benefit-cost ratio for all three adaptation actions: • Low climate change–slow growth scenario: **9.1** • High climate change–rapid growth scenario: **38.1** Present value of total residual damages post-adaptation (in 2008 $): • Low climate change–slow growth scenario: $4.6 billion • High climate change–rapid growth scenario: $37.1 billion

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Ochuodho et al. (2012) (national and by province)	Pessimistic (worst-case) and optimistic (best-case) impacts on timber supply from forest fires, pests and diseases; changes in forest productivity	1) Increasing pest prevention and control 2) Increasing forest fire prevention, control and suppression 3) Planting alternative species that are more suitable for future conditions Aggregate adaptation costs for all three actions (present value for the period 2010–2080, in 2008 $, range reflects best-case and worst-case scenarios): • Low climate change–slow growth scenario: $1.3–3.4 billion • High climate change–rapid growth scenario: $2–5.3 billion	Net present value for 70 years (2010–2080) Constant discount rate: 3% per annum In 2008 $	Combined net present value for all three adaptation actions (in 2008 $; range reflects best-case and worst-case scenarios): Low climate change–slow growth scenario: **$16.6–19.6 billion** High climate change–rapid growth scenarios: **$171.2–243.1 billion**

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Health				
NRTEE (2011) (Toronto)	Premature deaths associated with warmer summers and poorer air quality	1) Green roofs: reduce the urban heat-island effect by 1°C through widespread adoption of green roofs 2) Improve air quality: install pollution control technologies to eliminate ozone-forming emissions attributable to climate change Present value of adaptation costs (in 2008 $): 1) $7.3 billion (installations over the period 2035–2050, maintained through 2059) 2) $0.7 to $3.1 billion (installations over the period 2050–2059 under low and high climate change scenarios)	Present value for 10 years (2050–2059) Constant discount rate: 3% per annum In 2008 $	Benefit-cost ratio for option 1): • Low climate change–slow growth scenario: <**0.3** • High climate change–rapid growth scenarios: >**0.3** Benefit-cost ratio for option 2): • Low climate change–slow growth scenario: **4.0** • High climate change–rapid growth scenario: **1.6** Present value of residual damages post-adaptation (in 2008 $) for option 1): • Low climate change–slow growth scenario: $2.0 billion • High climate change–rapid growth scenarios: $4.2 billion Present value of residual damages post-adaptation for option 2): • No residual damages since it is assumed that the actions fully offset the health impacts of climate change

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
		Mining		
Rodgers and Douglas (2015) (Glencore's Sudbury Integrated Nickel Operation, Ontario)	Extreme rainfall and flooding; high and low water levels	Unknown options to manage five environmental triggers: 1) high water levels; 2) low water levels; 3) intense rainfall event; 4) low flood risk; 5) high flood risk Adaptation costs not specified	Payback over 39-year period Constant discount rate: 2% per annum	Payback threshold achieved by adaptation actions to manage environmental triggers 2), 3) and 5)
Perrin et al. (2015) (Tibbitt to Contwoyto Winter Road, Northwest Territories)	Impact of changes to length of operating season (late opening, early closure, no opening) for Tibbitt to Contwoyto Winter Road, a mine access road built mainly over frozen lakes in NWT	1) flexible scheduling (shorter season) 2) increased ice road construction and maintenance 3) increased portage construction and maintenance 4) increased ramp construction and maintenance Present value of adaptation costs (in $ million) (mean, 10th and 90th percentiles) for each option: 1) $44, $28 to $59 2) $5.8, $5.2 to $6.4 3) $5.3, $4.7 to $5.8 4) $0.3, $0.2 to $0.4	Present value over 35 years Constant discount rate: 4% per annum Price basis not specified	Net present value for the package of actions ($ million) (mean, 10th and 90th percentiles): **$160**, **-$30** to **$305** The above net present values reflect the difference in present-value costs between a "critical conditions scenario" (including the costs of modal shift and production losses at mines) and an "adaptive scenario" (with the four adaptation actions)

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
		Water levels		
Larrivée et al. (2016) (St. Lawrence River, Quebec)	Impact of low water levels in the St. Lawrence River on maritime transport; municipal water treatment; ecological services and fishing; recreational boating and tourism; hydroelectric generation; and waterfront property values	Options related to marine transport: 1) dredging 2) minimizing under-keel clearance 3) a combination of both Present value of adaptation costs (in 2012 $) for each option: 1) $8.8 million 2) $3.2 million 3) $12 million	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Net present value (in 2012 $) and benefit-cost ratio in brackets for each option, with the range defined by two “what if” hydrological scenarios: (a) critical annual flows gradually reached by 2040s, recovering partially thereafter, and (b) flows in summer and autumn lower than reference by 2020: 1) **$37–26.1 million** (**1.5–1.4**) 2) **$24.3–20 million** (**1.9–1.7**) 3) **$46.4–26.2 million** (**1.5–1.3**)
		Options related to municipal water treatment: • Modifying or replacing existing pumps with those capable of functioning at lower levels • Increasing or reconfiguring intake systems to reduce the risks of head loss and hydraulic constraints Present value of adaptation costs for two case study municipal water treatment plants (2012 $ million): • Plant 1: $0.1 million • Plant 2: $2.3 million		Net present value (in 2012 $) and the benefit-cost ratio in brackets: Plant 1: **-$0.1 million** (<**0.1**) Plant 2: **-$2.3 million** (<**0.01**) The above results are only for the hydrological “what if” scenario (a). Benefits only include market value of lost water production; they do not include the value of disrupted water supply to consumers

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Larrivée et al. (2016) (St. Lawrence River, Quebec) (continued)		Options related to ecological services and fishing: • Restoration of riparian zones • Restoration of the floodplain • Change in agricultural practices • More efficient wastewater treatment • Protection and restoration of habitat • Education and awareness Present value of adaptation costs for package of actions (in 2012 $): $560 million (optimistic cost: $345 million, pessimistic cost: $1,005 million)		Net present value (in 2012 $) and benefit-cost ratio in brackets for the package of actions: • For hydrological scenario (a) and based on pessimistic adaptation costs: **$225 million** (**1.2**) • For hydrological scenario (b) and based on pessimistic adaptation costs: **$2,265 million** (**3.3**)

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Dorling and Hanniman (2016) (Lake Michigan-Huron)	Impacts of low water levels (worst-case scenario)	1) submerged sills (+21 cm water level) 2) fixed rock-filled dikes (+16 cm) 3) parallel dykes and weirs (+16 cm) 4) inflatable flap gates (+16 cm) 5) hydrokinetic turbines (+19 cm) Present value adaptation costs (in 2012 $ US): 1) $40.6 million (no delay, staged construction) to $64.3 million (20-year delayed, non-stage construction) 2) $55.4 million to $47.4 million 3) $102.6 million to $78.0 million 4) $145.6 million to $83.1 million 5) $215.8 million to $140.4 million	Net present value for two construction scenarios: construction now (2015–2064) and construction delayed (2015–2084) Constant discount rate: 4% per annum In 2012 $ US	Range in net present value for each option (in 2012 $ US) across the two construction scenarios: 1) **$235 million** to **$50 million** 2) **$55 million** to **$45 million** 3) **$100 million** to **$80 million** 4) **$135 million** to **$5 million** 5) **$125 million** to **-$25 million**

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
		Agriculture		
Berry et al. (2017) (Pelly's Lake, Manitoba)	Impact of water stress (water availability) on agricultural crop yields (canola, wheat, alfalfa, barley)	Water storage retention ponds at Pelly's Lake and irrigation system Costs of retention pond and irrigation infrastructure (in 2015 $): $160.00 per hectare	Gross income and gross margin per hectare (undiscounted) In 2015 $	Average difference in crop gross margins without irrigation and with ponds and irrigation (and associated costs) for the period 2050–2059 (in 2015 $ per hectare): • RCP2.6: **-148** • RCP4.5: **-146** • RCP8.5: **-147** Average difference in crop gross margins without irrigation and with ponds and irrigation (and associated costs) for the period 2090–2099 (in 2015 $ per hectare): • RCP2.6: **-146** • RCP4.5: **-147** • RCP8.5: **-148** The availability of irrigation water increased crop production, but the resultant increase in gross income was insufficient to offset the costs of the ponds and irrigation system.

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Winter recreation – resort skiing				
DaSilva et al. (2019) (Mont Orford, Mont Sutton and Bromont Montagne, Québec)	Impact on the start of the ski season, the length of ski season, the skiable area and snow conditions for three ski resorts in Quebec	Options for Bromont Montagne: B1) Increase snow-making capacity B2) Synthetic ski slope B3) Diversify activities for corporate clients Options for Mont Sutton: S1) Increase snow-making capacity S2) Upgrade infrastructure to enhance quality of experience S3) Develop hosting capacity S4) Develop mountain biking capacity Options for Mont Orford: O1) Optimize existing snow-making capacity O2) Increase snow-making capacity O3) Extend opening hours on portions of hill O4) Increase beginner and intermediate slope capacity O5) Invest in summer activities O6) Regional coordination of activities offered	Net present value over the period 2020–2024 to 2045–2049 Constant discount rate: 4% In 2015 $	$ values for estimated net present values were not provided; the study only indicated whether adaptation actions had a positive or negative net present value. Only snow-making optimization measures at Mont Orford (O1) had a positive net present value (i.e., passed a cost-benefit test). This result holds across all 10 emissions scenarios considered in the analysis.

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Coastal areas				
NRTEE (2011) (national and by province)	Impacts of permanent flooding from sea-level rise and temporary flooding from storm surges	1) "Wise development planning": prevent new development in areas that will be at risk of flooding 2) Strategic retreat: rebuild homes in areas that are not prone to flooding Adaptation costs assumed to be zero for options 1) and 2)	Net present value for 90 years (2010–2100) Constant discount rate: 3% per annum In 2008 $	Net present value for option 1) (in 2008 $): • Low climate change–slow growth scenario: **$4.3 billion** • High climate change–rapid growth scenario: **$55.1 billion** Net present value for option 2) (in 2008 $): • Low climate change–slow growth scenario: $16.7 billion • High climate change–rapid growth scenario: $173 billion Present value of residual damages post-adaptation (2008 $) for option 1): • Low climate change–slow growth scenario: $13.2 billion • High climate change–rapid growth scenario: $127 billion Present value of residual damages post-adaptation (2008 $ billion) for option 2): • Low climate change–slow growth scenario: $0.9 billion • High climate change–rapid growth scenario: $9.1 billion

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Wilson et al. (2012) (Tantramar region of Southeast New Brunswick)	Impact of storm surge flooding	1) Dyke top-up 2) Relocation of infrastructure 3) Dyke top-up and relocation Present value adaptation costs (in 2000 $) for the above options: 1) $1.3 million 2) $10.3 million (relocation occurs over 20 years) 3) $11.5 million	Net present value for 100 years (2000–2100) Constant discount rate: 4% per annum In 2000 $	Net present value (in 2000 $) and benefit-cost ratio in brackets for each option: 1) **$40 million** (**31.0**) 2) **$20 million** (**2.9**) 3) **$35 million** (**4.0**) Present value of residual damages post-adaptation for each option (in 2000 $): 1) $19 million 2) $29.3 million 3) $12.7 million

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Parnham et al. (2016) (Chignecto Isthmus, Nova Scotia and New Brunswick)	Impact of sea-level rise, storm surge and coastal flooding	1) Raising existing agricultural dykes to 10 m 2) Combination of raising dykes to 10 m, shortening sections and raising infrastructure 3) Build new engineered dykes on top of existing dykes 4) Build new engineered dykes (shortened sections, protect public infrastructure only) 5) Build new engineered dykes (shortened sections, protect all infrastructure) 6) Relocate road	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio (no trade impacts case) for each option: 1) 0.5 2) 0.6 3) 1.1 4) 0.9 5) 1.5 6) 0.3 Benefit-cost ratio (trade impacts case) for each option: 1) 1.8 2) 1.9 3) 3.9 4) 3.2 5) 5.0 6) 1.0

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Parnham et al. (2016) (Halifax Harbour, Nova Scotia)	Impact of sea-level rise, storm surge and coastal flooding	1) Build seawall 2) Raise structures	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio (road and no trade impacts case) for each option: 1) **0.01**–**0.08** 2) **0.01**–**0.50** Benefit-cost ratio (rail and trade impacts case) for each option: 1) **1.8**–**2.6** 2) **0.5**–**4.3**
Parnham et al. (2016) (North Cape Coastal Drive, Kildare, Prince Edward Island)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	1) reactive, business as usual 2) planned (minimum level of adaptation: shoreline stabilization) 3) planned (medium level of adaptation: install a dyke to protect park) 4) planned (maximum level of adaptation: use of most appropriate adaptation option to maintain current activities) 5) relocate park, seasonal residents stay 6) abandon park, seasonal residents leave	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio for each option: 1) **0.9** 2) **1.0** 3) **0.8** 4) **0.5** 5) **0.6** 6) **1.2**

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Parnham et al. (2016) (Tracadie Harbour, Prince Edward Island)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	1) reactive, business as usual 2) planned (medium level of adaptation: install a dyke) 3) planned (maximum level of adaptation: install a dyke and raise buildings and roads) 4) close wharf, protect private property 5) abandon all	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio for each option: 1) 0.8 2) 0.4 3) 0.6 4) 0.3 5) 0.3
Parnham et al. (2016) (Bay Bulls – Witless Bay, Newfoundland)	Impact of sea-level rise, storm surge and coastal flooding	Engineered solutions across six sites, mainly involving raising or relocating infrastructure	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio: 0.01 to 20.6 (depending on site and adaptation)
Parnham et al. (2016) (Marystown, Newfoundland)	Impact of sea-level rise, storm surge and coastal flooding	Engineered solutions across six sites, mainly involving raising roads, land and buildings, and building seawalls	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio: 0.01 to 20.5 (depending on site and adaptation)

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Aubé et al. (2016) (Le Goulet, New Brunswick)	Impact of sea-level rise, storm surge and coastal flooding, as well as erosion	1) Dyke 2) Beach nourishment 3) Beach nourishment with breach	Net present value for 100 years (2016–2116) Constant Unknown price basis	Benefit-cost ratio for each option: 1) 0.6 2) 1.9 3) 1.6
Aubé et al. (2016) (Sainte-Marie-Saint-Raphaël, Cap-Bateau, Pigeon Hill, New Brunswick)	Impact of sea-level rise, storm surge and coastal flooding, as well as erosion	1) Relocation of homes at risk 2) Build erosion controls	Net present value for 100 years (2016–2116) Constant discount rate: 3% per annum Unknown price basis	Benefit-cost ratio for each option: 1) 0.3 2) 0.4
Aubé et al. (2016) (Shippagan and Pointe-Brûlée, New Brunswick)	Impact of sea-level rise, storm surge and coastal flooding, as well as erosion	1) Change in zoning to establish retreat and accommodation zone 2) Change in zoning, assuming no impact on property values	Net present value for 100 years (2016–2116) Constant discount rate: 3% per annum Unknown price basis	Benefit-cost ratio for each option: 1) 1.6 2) 2.2
Circé et al. (2016a) (Percé, Quebec)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	1) Beach nourishment 2) Planned retreat	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Range of benefit-cost ratios for each option across coastal segments: 1) 1.62–68.4 2) 1.0–1.4

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Circé et al. (2016a) (Maria, Quebec)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	1) Beach nourishment and groynes 2) Planned retreat and raising infrastructure	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Range of benefit-cost ratios for each option across coastal segments: 1) 1.1* 2) 1.1–3.6
Circé et al. (2016a) (Carleton-sur-Mer, Quebec)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	1) Beach nourishment 2) Planned retreat 3) Beach nourishment and groynes 4) Raising infrastructure 5) Planned retreat and raising infrastructure	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Range of benefit-cost ratios for each option across coastal segments: 1) 2.1* 2) 1.3* 3) 1.6* 4) 1.7* 5) 0.3–1.8
Circé et al. (2016a) (Îles-de-la-Madeleine, Quebec)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	1) Beach nourishment 2) Riprap 3) Planned retreat	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Range of benefit-cost ratios for each option across coastal segments: 1) 25.8* 2) 1.1–4.6 3) 1.0–1.7

STUDY, LOCATION	CLIMATE CHANGE IMPACTS	ADAPTATION OPTIONS	TIME FRAME, DISCOUNT RATE AND PRICES	ECONOMIC PERFORMANCE OF ADAPTATIONS
Circé et al. (2016a) (Kamouraska, Quebec)	Impact of sea-level rise, storm surge and coastal flooding, plus coastal erosion	Planned retreat and raising of infrastructure	Net present value for 50 years (2015–2064) Constant discount rate: 4% per annum In 2012 $	Benefit-cost ratio: **1.4**

Note: In the final column, for each identification, numbers in green font indicate that adaptation actions under consideration passed an economic efficiency test (i.e., the estimated net present value (NPV) > 0 or the BCR > 1); numbers in red font indicate that adaptation actions under consideration failed an economic efficiency test (i.e., the estimated NPV < 0 or the BCR < 1).

*Where only the value is listed, the adaptation option in question was only used in one coastal segment.

Appendix 6.5: Using equity weights to account for the distribution of costs and benefits

If people receiving benefits from an adaptation action or bearing the costs of the action belong to different income classes, it is possible to explicitly account for this by applying distributional weights according to their relative income levels. The weight attached to a person in group i with annual income Y_i is given as w_i, where:

$$w_i = \left[\frac{\bar{Y}}{Y_i} \right]^{\varepsilon}$$

And $\bar{Y}$ is the average income of the chosen reference group (e.g., the third income quintile) and ε is referred to as the inequality aversion parameter. Estimates of ε have been made in the literature indicating a central estimate in the range of 1.5 [1.0-2.0] (Groom and Maddison, 2018).

The following example shows how the weights would work. Assume the population of interest has an average income of $20,000 per annum. The weights to be attached to benefits accruing to individuals at different income levels are shown in the table below:

	WEIGHT	
INCOME ($)	ε = 1	ε = 2
5,000	4	16
10,000	2	4
20,000	1	1
50,000	0.4	0.16
100,000	0.2	0.04

A reduction in climate-related damages of $1 to a person with an income of $5,000 would be given a value of $4 in the economic analysis if ε is assumed to be one and $16 if ε is assumed to be two, and so on for other income levels.

CHAPTER 7

Sector Impacts and Adaptation

NATIONAL ISSUES REPORT

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Canada

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Key messages

Climate change affects almost every economic sector in Canada (*see* Section 7.1)

Virtually every sector of the Canadian economy is affected, directly and/or indirectly, by climate change. Assessments of risks and opportunities that consider connections within and between sectors can help establish priorities for investments in adaptation actions.

Sustainable forest management is challenged by wildfires and pest outbreaks (*see* Section 7.2)

The forest sector is dealing with a wide range of climate change risks, from pest outbreaks to wildfire and long-term species shifts. The impacts of extreme events, such as wildfire, highlight the need for actions that build more resilient forests and communities, and that contribute to climate change mitigation.

Changes to ocean health are affecting fisheries and associated livelihoods (*see* Section 7.3)

Changes in ocean temperature and chemistry are already affecting fish populations. While some future impacts will be positive, many will present challenges to harvesters' economic livelihoods and regulators' responsibility for sustaining ocean health. Effective management depends upon realistic models of the future abundance and distribution of commercial species in response to both climatic and non-climatic stressors.

Climate change brings benefits and threats to the agriculture sector (*see* Section 7.4)

Climate change brings both opportunities and challenges to Canada's agricultural sector. Longer growing seasons and the potential to grow crops farther north may benefit agriculture, while changes in water availability, extreme weather events, and pests and diseases will present challenges. Adaptation actions that enhance climate resilience and consider the linkages between agriculture and interconnected sectors, such as water management and transportation, will benefit both local sustainability and global food security.

Climate change brings new environmental challenges for mining (*see* Section 7.5)

Impacts on the chemical and physical stability of tailings containment and reclamation structures are among the greatest climate-related challenges to the Canadian mining industry. Failure of such structures can lead to severe environmental contamination and present risks for surrounding communities and ecosystems. Considering long-term climate change at the design phase of mining projects is necessary to reduce these risks.

Each link of the energy value chain can be vulnerable to climate change (*see* Section 7.6)

Changing climate affects energy demand and the full energy value chain, from exploration and production through to transmission and distribution. Climate risks can be integrated into current business planning by considering co-benefits, no-regret options and incremental approaches. Climate resilience needs to be a key consideration in converting to low-carbon energy systems.

Extreme weather events impact transportation, disrupting supply chains (*see* Section 7.7)

Road, rail, marine and air transportation in Canada are vulnerable to "extreme weather events and slow-onset climate change, with major disruptions having significant economic and social impacts. To fully assess these impacts, linkages between transportation systems, and between transportation modes and a wide range of other economic sectors, need to be accounted for. Coordinating adaptation responses across jurisdictions and sectors will benefit transportation asset owners, operators and those dependent on vulnerable supply chains and corridors.

Climate change is leading to transformational changes in tourism (*see* Section 7.8)

All tourism destinations need to adapt to climate change impacts on tourism assets and altered competitiveness within the highly interconnected tourism economy. While Canadian tourism competitiveness is expected to increase under climate change, the specific market and regional implications of this change for national competitiveness remain under-researched. Winter and northern tourism and recreation are particularly sensitive to climate variability, and transformational changes in ski, snowmobile and Arctic cruise tourism are expected.

Increased private sector involvement will accelerate adaptation across sectors (*see* Section 7.9)

Despite growing awareness of climate change impacts, there is no widespread evidence of corporate adaptation in Canada. When adaptation does occur, it tends to focus on short-term actions to address physical risks, such as disruptions in construction and interruptions in supply chains. Increased involvement of the private sector would accelerate adaptation in Canada as a whole.

7.1 Introduction

Virtually every sector of the Canadian economy is affected, directly and/or indirectly, by climate change. Assessments of risks and opportunities that consider connections within and between sectors can help establish priorities for investments in adaptation actions.

It is increasingly evident that climate change is impacting Canada's economy as a whole, and that these impacts will increase in future (Canadian Council of Academies, 2019). Adaptation will be necessary across all sectors to limit climate risks and, in some cases, to benefit from new opportunities. Proactive adaptation enables innovation and growth, and can enhance economic competitiveness (Kovacs and Thistlethwaite, 2014). Very few studies have undertaken quantitative economic analysis of the impacts of specific climate scenarios on Canadian business and industry (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter; Eyzaguirre, 2016), but research elsewhere demonstrates that costs accelerate with continued warming (IPCC, 2014). Additionally, at higher rates of climate change, adaptation options become increasingly limited, presenting critical risks ranging from local economic viability to global food security (IPCC, 2019, 2018, 2014).

From a Canadian perspective, most sectoral research on impacts and adaptation has focused on food and natural resource sectors where climate change directly affects primary production, such as agriculture, fisheries, forestry and hydroelectricity generation (Warren and Lemmen, 2014). The economic significance of these sectors is amplified at both the local scale, with many Canadian communities deriving 80% or more employment income from these sectors (*see* Rural and Remote Communities chapter), and on the global scale, where Canada is among the world leaders in agriculture, forestry and mineral exports.

Less attention has been paid to other sectors of Canada's economy, with the exception of human health (Berry et al., 2014). However, there is growing recognition that climate-related health and social impacts on communities and workers, as well as climate impacts on supply chains and other infrastructure, represent significant material and financial risks throughout the economy (Canadian Council of Academies, 2019). As a result, a growing body of literature on these other sectors is emerging (*see* Climate Disclosure, Litigation and Finance chapter).

Previous sectoral assessments conducted in Canada, such as Warren and Lemmen (2014)—particularly chapters 4, 5 and 6—highlight:

- Vulnerabilities to both extreme weather events and to slow-onset climate changes;
- Amplified impacts in northern and remote communities;
- Opportunities that climate change presents for many sectors, in addition to the changing nature of climate risks;
- Increased implementation of climate adaptation measures and expanded engagement of industry, governments and civil society; enhancing both social and economic resilience;
- Processes that can help advance adaptation actions, including risk disclosure, environmental assessment and sustainable management reporting;

- Interdependencies between sectors, with transportation systems being particularly important; and
- A lack of information related to indirect impacts of climate change, including those related to consumer demand, supply chains, real estate or other assets, legal liability and government regulation.

This chapter builds on the findings of Warren and Lemmen (2014) and other relevant Canadian assessments (e.g., Palko and Lemmen, 2017) by examining key climate change impacts and adaptation in seven sectors of Canada's economy—forestry, agriculture, fisheries, energy, mining, transportation and tourism—as well as broad perspectives on corporate adaptation. Issues related to human health are not included in this chapter, as they are addressed in a separate assessment report (*see Health of Canadians in a Changing Climate Report*). The authors focused on a limited number of priority issues identified through assessment of the breadth of available knowledge. As a result, the subsequent sections of this chapter do not provide a comprehensive assessment of climate change impacts and adaptation responses within each sector, but rather focus on topics where knowledge has advanced recently and where the assessed knowledge relates directly to the ongoing decision-making process.

7.2 Sustainable forest management is challenged by wildfires and pest outbreaks

The forest sector is dealing with a wide range of climate change risks, from pest outbreaks to wildfire and long-term species shifts. The impacts of extreme events, such as wildfire, highlight the need for actions that build more resilient forests and communities and contribute to climate change mitigation.

Climate variability and extreme weather events associated with climate change are challenging forest management by limiting access to forest resources and increasing operational costs. More frequent wildfires and forest pest infestations are constraining local timber supplies and impacting the social and economic well-being of forest communities. In addition, the forest sector is facing longer-term climate impacts, such as changes in tree species composition, stand structure, productivity and health. In response to these and other challenges, such as changing social values and market demand, forest companies are addressing multiple environmental, economic and social needs simultaneously. Adaptive, risk-based management approaches that apply research, monitoring and evaluation will help inform future management policies to promote healthy, resilient forests and enhance carbon storage.

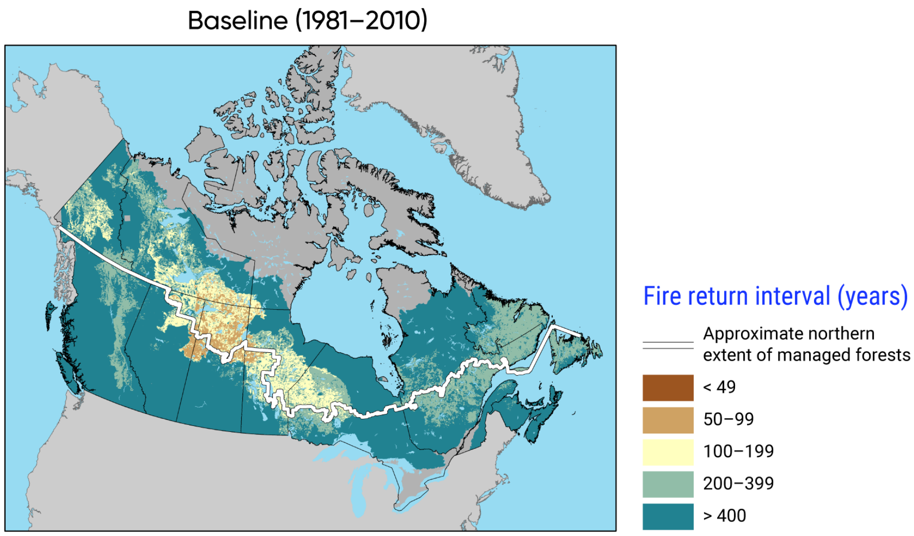
7.2.1 Introduction

The Canadian forest sector is sensitive to the impacts of climate on ecosystem goods and services. In the short term, projected increases in temperature will likely surpass the potential moderating effects of increasing precipitation on fire weather (Zhang et al., 2019), leading to an increased risk of wildland fire and drought (Boucher et al., 2018; Boulanger et al., 2017; Flannigan et al., 2009). Climate change is also a critical driver of progressive disturbances, such as pest infestations, which influence the likelihood of immediate disturbance events, while also affecting long-term forest structure and composition (Sulla-Menashe et al., 2018; van Lierop et al., 2015; Price et al., 2013; Sturrock et al., 2011; Burton, 2010). The cumulative effects of these changes decrease the health and resilience of Canada's forests, constraining timber supply and increasing risks to the forest sector (Boucher et al., 2018; Taylor et al., 2017; McKenney et al., 2016; Gauthier et al., 2014; Price et al., 2013; Coulombe et al., 2010; Williamson et al., 2009). Better understanding of these projected changes will help the forest sector better prepare for both risks and opportunities.

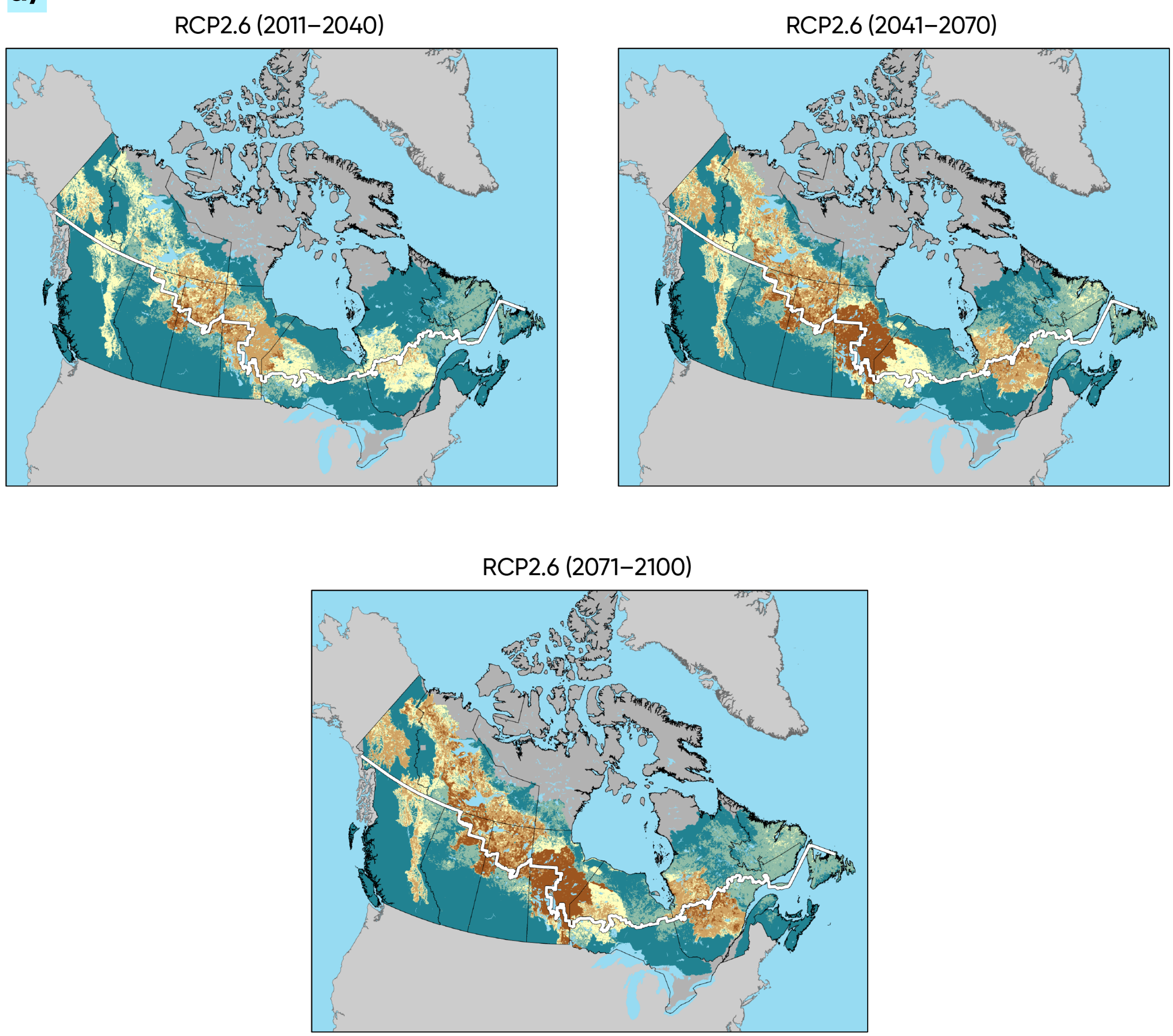
Past management responses to climate-related impacts in the forestry sector have tended to be reactive, as exemplified by responses to the mountain pine beetle outbreak in Western Canada (Jones and Preston, 2011; Bentz et al., 2010; Williamson et al., 2009). Recently, forest managers, policy specialists and researchers have developed an array of knowledge resources, tools, and protocols to help practitioners and stakeholders take a proactive approach to managing the impacts of a changing climate and related environmental and socioeconomic stressors. The phases of adaptive management are reviewed in a series of past assessments (Gauthier et al., 2014; Lemmen et al., 2014; Price et al., 2013; NRTEE, 2011; Williamson et al., 2009), recognizing that no single "road map" exists to guide the implementation of adaptation responses (Samy et al., 2015). This section builds upon past assessments by focusing on wildland fire in the context of recent events.

7.2.2 Impacts of wildfire

While forest fires are a natural and essential element of forest ecology, there is growing awareness of the dramatic impact that wildfires have on Canadians. As climate changes occur, fire regimes are changing, often with increasing frequency, severity and size (Mori and Johnson, 2013; Flannigan et al., 2009). Non-climate factors, such as forest condition, forest management practices, land cover (Marchal et al., 2017) and cumulative disturbances are also important considerations in explaining these increases. The fire season is becoming longer, starting earlier in the spring and ending later in the fall (Zhang et al., 2019; Hanes et al., 2018; Jolly et al., 2015; Flannigan et al., 2013), with more frequent fires (expressed by a shorter fire return interval) expected throughout this century (*see* Figure 7.1).


Baseline (1981–2010)
Fire return interval (years)
Approximate northern extent of managed forests
< 49
50–99
100–199
200–399
> 400

a)


RCP2.6 (2011–2040)
RCP2.6 (2041–2070)
RCP2.6 (2071–2100)

b)

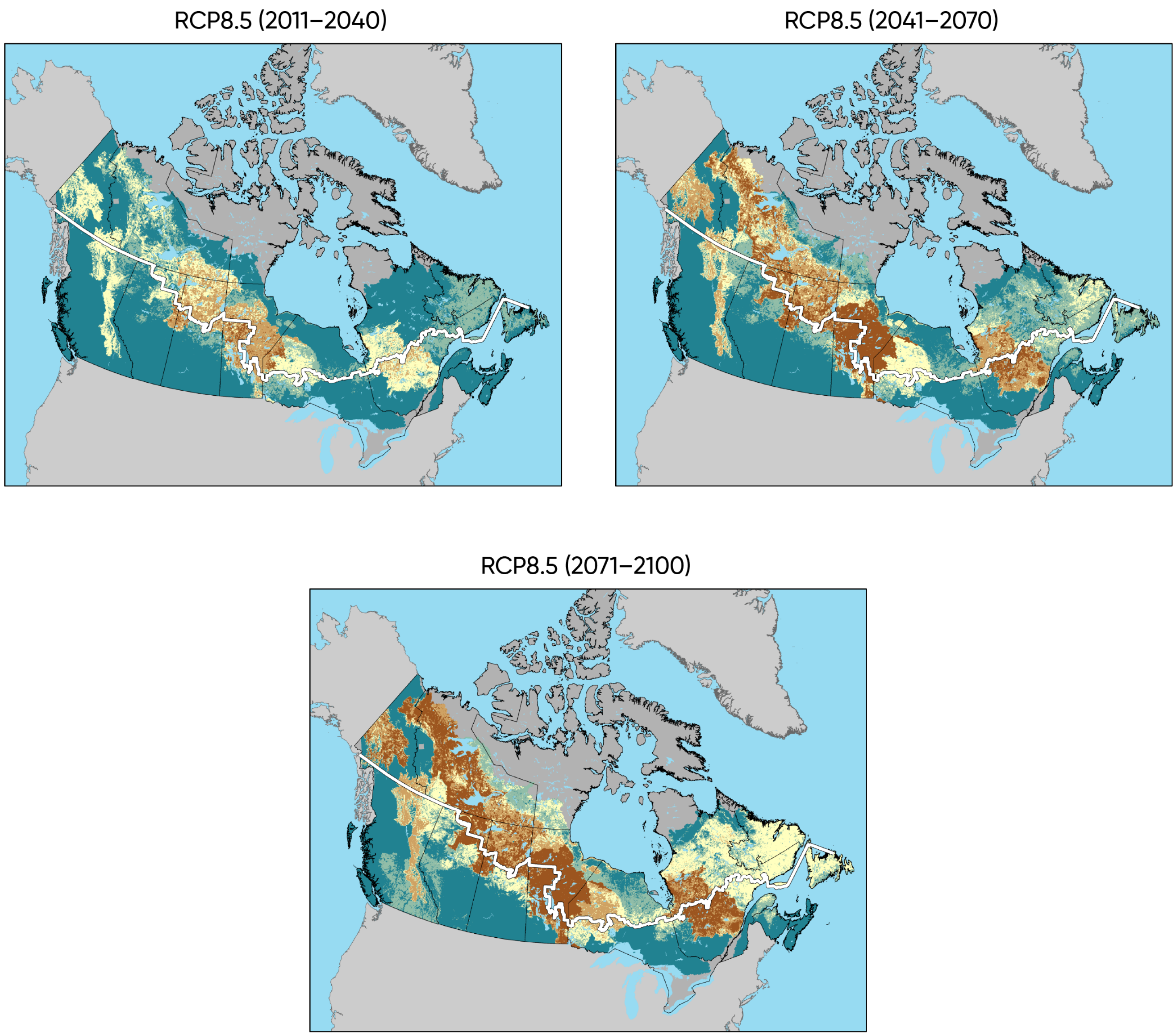


Figure 7.1: Interactive maps of baseline and projected fire likelihood in Canada, presented in terms of fire return interval (years), for two greenhouse gas (GHG) emissions scenarios: a) a low emissions scenario (RCP2.6) and b) a high emissions scenario (RCP8.5). Shorter fire return intervals (in brown and light brown) represent a higher fire likelihood, and longer cycles (in yellow, light and dark green) represent a low fire likelihood. The maps show local fire likelihood (pixels represent a 250 m² resolution) using the homogeneous fire regime zones of Boulanger et al. (2014) and display fire selectivity based on vegetation composition and stand age at the pixel level. Source: Boulanger et al., 2014.

Ecological impacts following wildfires include changes to forest stand structure, such as age class distribution and species composition (Price et al., 2013; Brown and Johnstone, 2012; Lynch, 2004). Shorter return intervals, in combination with growing fire severity, increase the risk of regeneration failure (*see* Figure 7.2; Whitman et al., 2019), and transitioning of forested areas to non-forested terrain (Boiffin and Munson, 2013; Price et al., 2013; Brown and Johnstone, 2012). Loss of tree cover on the landscape can lead to flooding and mass wasting in some areas (Bladon, 2018; Creed et al., 2016). Changes to fire regimes threaten not only timber supply (quality, quantity and tree species mix), but also the provision of ecosystem services, such as biodiversity, habitat for species at risk, carbon storage, water quality and water quantity (*see* Ecosystem Services chapter; Gauthier et al., 2014; Price et al., 2013). While it is difficult to predict how such changes will manifest locally, analysis of past mountain pine beetle infestations suggests that creating more resilient forests results in multiple benefits (Dymond et al., 2015).

Figure 7.2: Photo of a post-fire landscape at risk of regeneration failure: a site in the Northwest Territories, one year after a 2014 wildfire. This site had previously burned in 2004 and the short (10-year) interval between fires has led to a complete lack of tree recruitment. Poor regeneration is attributed to the absence of both seedlings and soil organic matter prior to the fire. Photo courtesy of Natural Resources Canada.

There is a growing awareness of the social impacts of wildland fire (McGee et al., 2015; Gill et al., 2013), including the numbers of wildfire evacuees (*see* Figure 7.3). Evacuations cause physical and mental health issues, disrupt the lives of evacuees and create economic stress on individuals and communities (McCaffrey et al., 2015; Beverly and Bothwell, 2011; Marshall et al., 2007; Morton et al., 2003). With more wildfires, health issues due to smoke are increasing well beyond the immediate vicinity of the fire (Liu et al., 2016; Reid et al., 2016; Finlay et al., 2012), and visibility issues are impacting transportation (Goodrick et al., 2013). To date, these impacts have disproportionately affected small and Indigenous communities: one third of all wildfire evacuees are Indigenous and over half of smoke-related evacuations involve Indigenous communities (*see* Rural and Remote Communities chapter; Sankey, 2018; Scharbach and Waldram, 2016; Christianson, 2015).

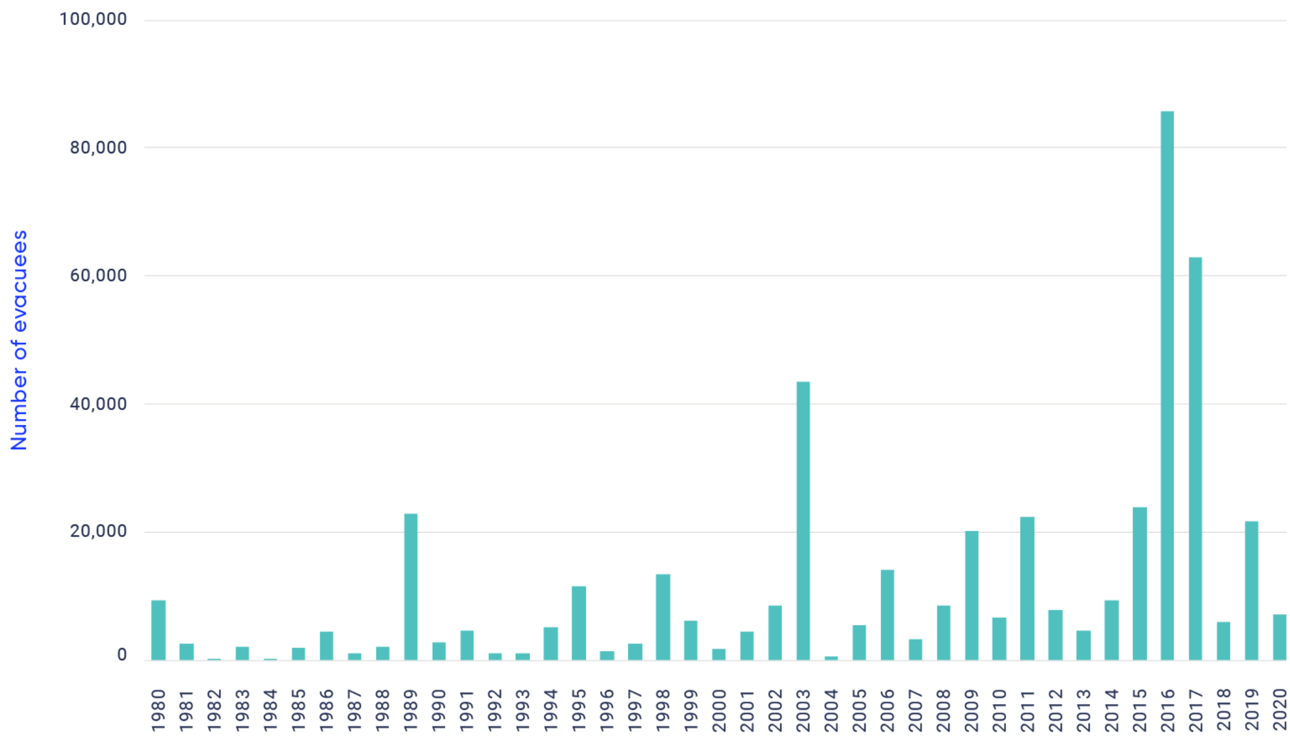


Figure 7.3: Number of wildfire evacuees in Canada (1980–2020). Many factors, including fire frequency, size and location relative to population density, influence the number of evacuees. British Columbia, Alberta, and Ontario have had the most evacuations from 1980 to 2020. Data source: Government of Canada, 2020.

Economic impacts associated with wildland fire are far-reaching. Direct costs, which include fire management and suppression activities (Rijal et al., 2018; Wotton et al., 2010), have increased from an average of $290 million per year in the early 1970s to about $1 billion annually in recent years (Natural Resources Canada, 2019, 2017). These costs are projected to further increase by over 100% by the end of the century under a high emissions scenario (Hope et al., 2016). Maintaining current effective levels of fire suppression appears to be unsustainable (Wotton et al., 2017; Hope et al., 2016). Climate change impacts and loss of timber supply have cascading economic impacts on the forest sector that are difficult to quantify (Ochuodho and Lantz, 2014). Other sectors also face direct costs from wildfires, including the following: evacuation expenditures; damage to infrastructure; shutdown of businesses and industries; insurance costs; and loss of forest ecosystem services (McGee et al., 2015; Gauthier et al., 2015; Peter et al., 2006). The increased emphasis on forests in the low-carbon economy highlights the importance of quantifying the costs associated with the release of greenhouse gases. There are also health costs associated with smoke and evacuation stress (Reid et al., 2016; McCaffrey et al., 2015; Beverly and Bothwell, 2011; Morton et al., 2003).

Catastrophic insurable losses due to extreme events such as wildfire are increasing. The Fort McMurray wildfire in 2016 was the largest insurance event in Canada, assessed at almost $4 billion (*see* Case Story 7.1; Insurance Bureau of Canada, 2019, 2016; Swiss Re Institute, 2018; Statistics Canada, 2017). This assessment vastly underestimates overall costs, given that uninsured costs for repairing and rebuilding for governments and homeowners can be three to four times those of private insurance companies (Dixon et al., 2018). The link between climate change and extreme events is clear (e.g., IPCC, 2012), with recent attribution analysis in Canada indicating that climate change has increased the likelihood of extreme dry conditions, extreme wildfire risk and the length of fire seasons (Kirchmeier-Young et al., 2017; Tett et al., 2017). All of these factors are relevant to the Fort McMurray wildfire (Zhang et al., 2019).

Case Story 7.1: The 2016 Fort McMurray (Horse River) wildfire

The Horse River wildfire began on May 1, 2016, seven kilometres outside of Fort McMurray, Alberta. Two days later, it entered Fort McMurray, destroying approximately 2,400 homes and displacing an additional 2,000 residents in three communities within the Wood Buffalo region (*see* Figure 7.4; MNP, 2017). Before it was controlled, the fire spread across northern Alberta into Saskatchewan, threatening First Nations communities, impacting Athabasca oil sands operations through lost oil production of approximately 47 million barrels—costing $1.4 billion in lost revenue (Antunes et al., 2016)—and consuming extensive forests and destroying critical infrastructure (MNP, 2017). The Insurance Bureau of Canada estimated insured losses at $3.9 billion, making it the costliest disaster in Canadian history and also one of the worst fire disasters internationally (Insurance Bureau of Canada, 2019, 2016; Swiss Re Institute, 2018).

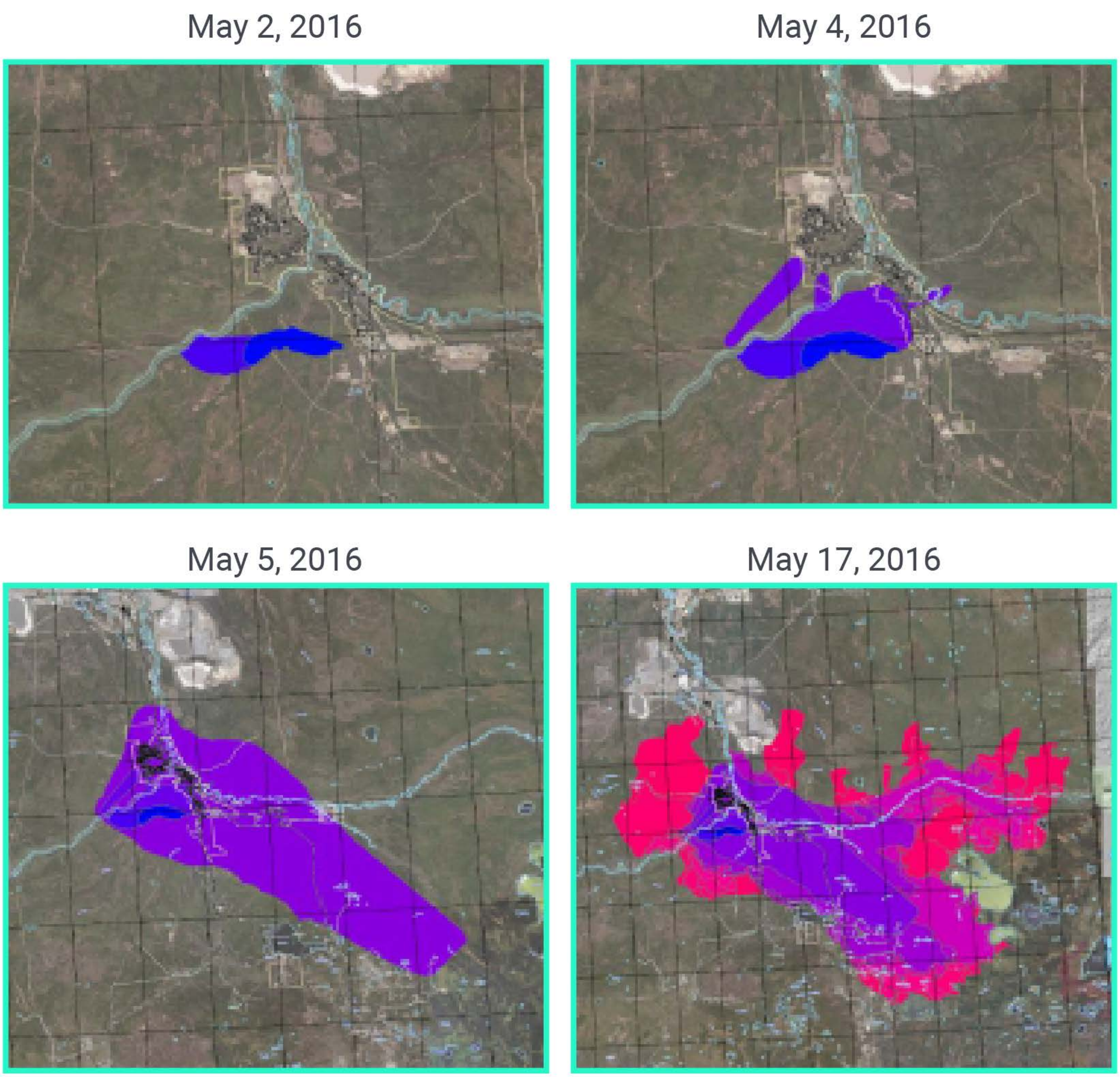


Figure 7.4: a) 2016 Horse River wildfire approach to Fort McMurray, Alberta; b) Maps outlining the growth of the 2016 Horse River Wildfire from May 2, 2016 to May 17, 2016. Source: Adapted from MNP, 2017.

Estimating the full costs of wildfires presents challenges due to the number of direct and indirect costs, ranging from economic damage to homes and infrastructure to the health care costs associated with atmospheric pollution from the fire and toxic discharges into watersheds (*see* Table 7.1). The Horse River experience illustrates how the impacts of wildfire can quickly expand beyond the forest sector to include numerous other sectors and disciplines, and highlights the importance of collaboration between institutional partners in dealing with the full impacts of climate change.

Table 7.1: Examples of direct and indirect costs associated with the Fort McMurray (Horse River) wildfire

DIRECT COSTS (EXAMPLES)
Suppressing and extinguishing wildfire across multiple jurisdictions
Evacuation activities, including the coordination and support of evacuees
Law and order maintenance during the evacuation
Damage to personal property
Damage to business infrastructure
Damage to public infrastructure (gas, power and telephone lines)
Commercial timber losses
INDIRECT COSTS (EXAMPLES)
Loss of oil production
Loss of non-oil industrial production, including retail and other commercial sectors
Unemployment (lost wages and salaries)
Demographic shifts (population decline and loss of productive workforce)
Social service costs, including long-term health care and family related-issues
Greenhouse gas emissions, the release of pollutants, and other impacts on ecosystem services
Insurance rate increases
Source: Based on Subedi et al., 2016.

7.2.3 Adaptation

Since the risks associated with wildfire and other climate impacts have effects beyond the forest sector, implementing adaptation measures requires the involvement of stakeholders across multiple sectors (Furness and Nelson, 2016; Nelson et al., 2016). Some adaptation options mentioned below are specific to wildfire, while others contribute to increasing the overall resilience of forests and forest communities (*see* Edwards et al., 2015 and Gauthier et al., 2014 for compendiums of adaptation measures).

Various adaptation options are available to reduce the risk and impacts of forest disturbances such as wildfire (Leduc et al., 2015; McGee et al., 2015; Blackwell et al., 2008). For example, fire risk can be reduced through active fuel management, involving thinning, debris removal and prescribed burning (Astrup et al., 2018; Schroeder, 2010; Ohlson et al., 2006; Spittlehouse, 2005), and adjusting harvest schedules to favour older and insect-damaged stands (Dymond et al., 2015; Raulier et al., 2014). Regeneration planning could include a greater proportion of more fire-tolerant species and deciduous trees (Bernier et al., 2016).

At the local level, FireSmart activities (Hirsch et al., 2001), such as creating fire breaks around communities, building with fire-resistant materials, and cleaning up debris around properties to reduce fuel load, help increase resilience to wildland fire (FireSmart Canada, 2019a, 2019b, 2018; Spittlehouse, 2005). Communities are actively improving their emergency preparedness by creating plans for culturally-sensitive evacuations and hosting of evacuees (Scharbach and Waldram, 2016; Beardy's and Okemasis' Cree Nation, n.d.).

While a number of adaptation responses have been developed to reduce the costs resulting from the effects of wildfire on timber supply (Rijal et al., 2018; Leduc et al., 2015; Raulier et al., 2014; Raulier et al., 2013); addressing the broader economic impacts of wildland fires extends far beyond the forest sector (Orwig, 2016). For example, the insurance sector is examining the impact of wildland fires on mining, forestry, energy, agriculture, transportation and utilities, and is collaborating with organizations such as FireSmart (Hirsch et al., 2001) to incentivize actions to reduce fire risks around communities and infrastructure.

The status of implementation provides a benchmark for measuring adaptation progress in the forest sector. The Canadian Council of Forest Ministers' Climate Change Task Force produced a series of nine interrelated reports (Canadian Council of Forest Ministers, n.d.), including a practical guidebook (Edwards et al., 2015), to support mainstreaming of climate change into forest management planning. Early adopters are using this guidebook to assess vulnerabilities and rank adaptation options based on current and future ability for implementation (Andrews-Key, 2018; Gatin and Johnston, 2017). Guidance documents have also been produced to help private woodlot owners adapt to a changing climate (Ontario Woodlot Association, 2015). National and regional climate change initiatives (e.g., Gatin and Johnston, 2017) include climate change strategies and action plans, and updated policies and regulations. Supportive research has placed an emphasis on integrated assessment approaches, drawing on expertise from a range of disciplines to complement ecological research with socioeconomic analyses.

7.2.4 Moving forward

Climate change is already affecting the forest sector, especially through extreme events such as wildfire. These effects are expected to continue and intensify, requiring greater efforts to implement adaptation measures. While no single road map exists to guide adaptation implementation, regional risk assessments in Canada have highlighted the need for integration of ecological, social and economic pressures beyond the forest sector. Integration and the capture of synergies across sectors can be greatly facilitated by adopting common data sources and scenarios (Environment and Climate Change Canada, 2018) as well as risk-based methods and frameworks (*see* Section 7.9; Johnston et al., 2020; ISO, 2018; Daniel et al., 2017; Calkin et al., 2014; Jones and Preston, 2011). Implementation of actions that enhance the climate resilience of forests is important for supporting the ecological, social and economic services that forests provide.

7.3 Changes to ocean health are affecting fisheries and associated livelihoods

Changes in ocean temperature and chemistry are already affecting fish populations. While some future impacts will be positive, many will present challenges to harvesters' economic livelihoods and regulators' responsibility for sustaining ocean health. Effective management depends upon realistic models of the future abundance and distribution of commercial species in response to both climatic and non-climatic stressors.

Climate change is increasing water temperatures and acidity, decreasing oxygen content and increasing the salinity of the world's oceans. Of these environmental variables, changes in temperature, dissolved oxygen and acidification will be responsible for most of the direct impacts on fisheries and aquaculture (farming of fish or shellfish) in Canada over the next few decades. These variables are driving, and will continue to drive, changes in distribution, productivity, reproduction and timing of seasonal events (e.g., moulting, migration, spawning and hatching) for many aquatic species. Extreme events, particularly abrupt warming events lasting many months, are also important considerations in aquatic management. Planning of adaptation measures needs to account for the complex interactions between various climate stressors, as well as non-climatic stressors such as fishing pressures.

7.3.1 Introduction

The critical role and climatic sensitivity of fisheries and aquaculture in food security at the global scale, and in local-scale resilience of coastal communities, are well established (Bindoff et al., 2019; Lemmen et al., 2016; Porter et al., 2014). An overview of climate change impacts on food production in Canada, and related adaptation actions, was presented by Campbell et al. (2014). For the fisheries sector, the researchers concluded that regional impacts from physical habitat changes, invading species, and societal responses will determine future patterns of use and overall economic implications. Aquaculture was noted as having the greatest scope for adaptation measures, making it less vulnerable and better positioned to take advantage of opportunities compared to capture fisheries, while traditional subsistence fisheries were deemed to be particularly vulnerable.

This section builds on the findings of Campbell et al. (2014) by focusing on near-term challenges for the sustainable management of marine ecosystems arising from physical habitat changes (e.g., warming, acidification, and lowering or depletion of dissolved oxygen), and highlights how climate change is being incorporated into scientific advice that informs fisheries and aquaculture management decisions. Greater details on the physical impacts of changing climate are described in [Chapter 7 of *Canada's Changing Climate Report*] (Greenan et al., 2019a). Impacts on freshwater recreational and commercial fishing and aquaculture are not discussed here, but it is clear that increased water temperatures and decreased pH and oxygen are already impacting many freshwater ecosystems. Additionally, it is noted that anadromous species will be subjected to negative impacts during their stay in freshwater, and therefore even marine fisheries will be affected by changes in freshwater ecosystems.

7.3.2 Water temperature

With a few exceptions, the internal temperature of fishes and crustaceans closely matches that of the water in which they live. As a result, temperature exerts a strong influence on their physiology (e.g., metabolism and growth) and aquatic animals are adapted to a species-specific temperature range. When mobile species encounter temperatures approaching their upper tolerance limit, they tend to move towards cooler, more optimal temperatures. Off the west coast of British Columbia, a persistent warming event from 2013 to 2015 had several ecosystem impacts (*see* Case Story 7.2).

Case Story 7.2: Impacts of the 2013–2015 marine heat wave on Canada's west coast

A well-documented warming event that started offshore of the west coast of British Columbia in 2013 was evident in coastal waters by the summer of 2015 (*see* Figure 7.5), with an increase in water temperatures of 3˚C above normal (Ross, 2016). This warming of coastal waters was accompanied by harmful algal blooms, record high levels of large gelatinous zooplankton and invasion by warm-water species (Chandler et al., 2016). The event may have had cascading ecosystem consequences, such as the extraordinary bloom of a colonial waterborne tunicate (an animal with no backbone that is rarely found north of California) observed along the entire west coast of North America in 2017 (Brodeur et al., 2018). While the specific causes are unknown, the 2013–2015 marine heat wave, coupled with favourable conditions for growth and reproduction, could have resulted in this unprecedented bloom. The bloom had substantial negative impacts on commercial and recreational fishing operations due to fouling of fishing gear (Brodeur et al., 2018), illustrating that anomalous events can have unforeseen impacts on coastal fisheries.

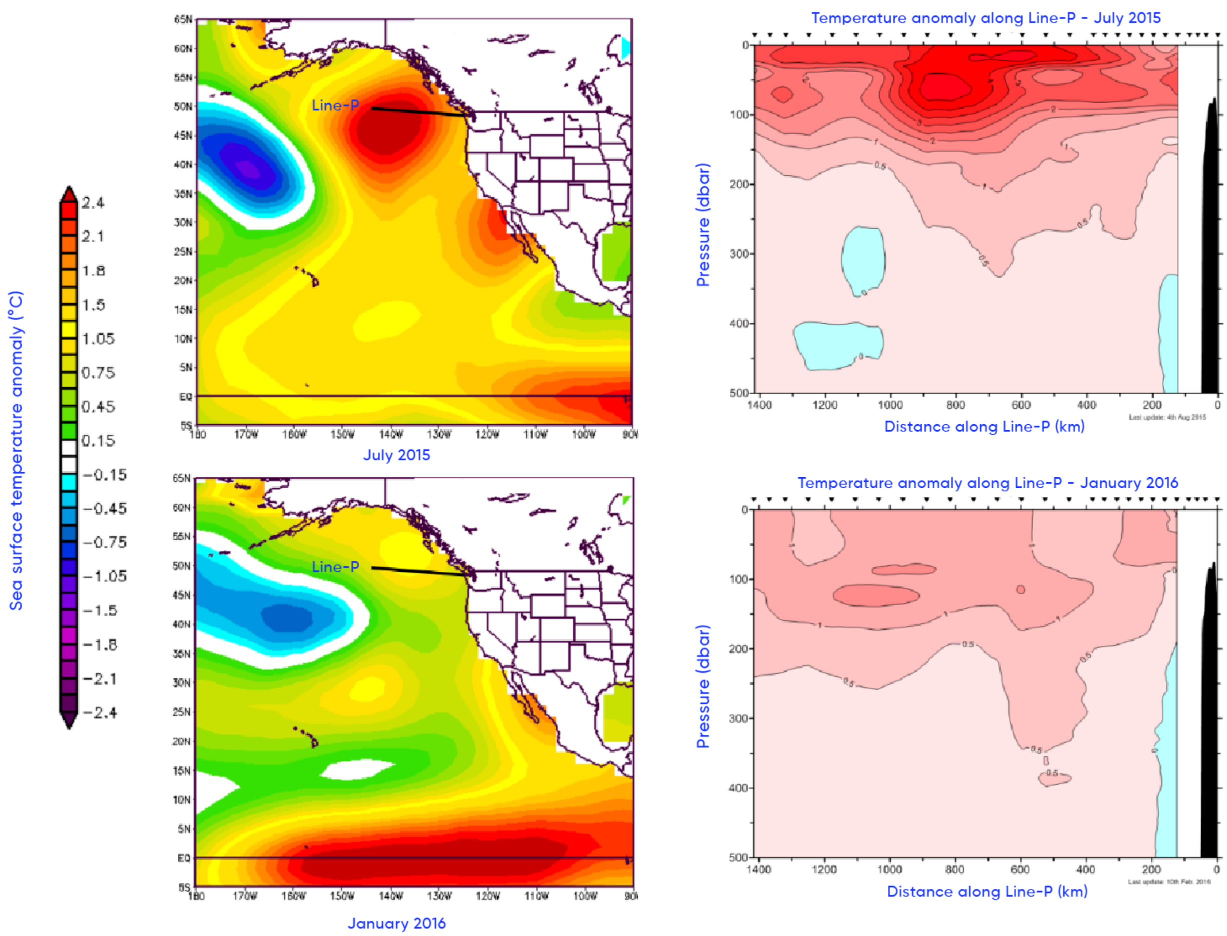


Figure 7.5: The left-hand panels show sea-surface temperature anomaly data (National Oceanic and Atmospheric Administration), including information from satellites, ships, and moored and drifting buoys. Temperature anomalies are the differences between the observed temperature and the long-term average temperature (both in °C) for a given location. The green, yellow and red colours represent above-average temperatures, whereas the blue and purple colours represent below-average temperatures. The right-hand panels show temperature anomalies by depth (in meters) along Line-P, as shown in the left-hand panels and starting near the southwest coast of Vancouver Island, BC, leading to the Ocean Station Papa (145°W, 50°N). The colours are demarcated by increments of 0.5°C. Source: Adapted from Chandler et al., 2016.

The general warming trends documented for the last century over most of the world's oceans have already resulted in distribution shifts (Mueter and Litzow, 2008). Changes in distribution of commercial species will cause changes in the location and success of fishing effort. Eventually, new species may replace old ones in the fisheries. Smaller movements or changes in abundance can also be observed at the regional scale, as fishes and crustaceans adjust their distribution to local changes in temperature (*see* Case Story 7.3).

Case Story 7.3: Response of snow crab to rapid warming in Atlantic Canada

Snow crab is a cold-water species with an upper thermal limit of 6–7°C. It is the second most valuable fishery in Atlantic Canada (Fisheries and Oceans Canada, 2018a). Its distribution has been shown to expand during cold periods and shrink in warmer periods (Ernst et al., 2005; Zheng and Kruse, 2000; Tremblay, 1997). An extreme warming event documented in the deep waters at the mouth of the Laurentian Channel off Nova Scotia, starting in 2012, propagated onto the Scotian Shelf, with temperatures reaching 7–9°C on the western Scotian Shelf (Brickman et al., 2018). This warming was accompanied by pronounced declines in catches in this fishing area, suggesting local mortality due to thermal stress in the absence of local colder refugia (Zisserson and Cook, 2017). The warming event also propagated into the deep channels of the Gulf of St. Lawrence and is still ongoing (Galbraith et al., 2018). In this ecosystem, changes in the distribution and abundance of snow crab and other important commercial cold-water species, such as Greenland halibut and Northern shrimp, have been partly caused by deep water warming of more than 1°C (Fisheries and Oceans Canada, 2018b, c, d).

Attribution of impacts must take into account the multiple climatic and non-climatic factors that affect species distributions. For example, fishing pressure, population size and bottom temperature all affect, to varying degrees, changes in the distribution of groundfish (Adams et al., 2018). This illustrates the importance of examining the joint role of fishing and climate in the distribution of fish stocks in order to provide sound scientific advice for management.

7.3.3 Dissolved oxygen

Fishes and invertebrates require oxygen to live, although they differ in their sensitivity to lack of dissolved oxygen (hypoxia). Each species has a minimum level of oxygen required for survival, with severe hypoxia resulting in habitat loss and changes in distribution for mobile species, and increased mortality for immobile (sessile) species (Breitburg et al., 2018). Moderate hypoxia limits the amount of energy that animals can spend (Claireaux and Chabot, 2016), which usually translates into reduced feeding and growth rates for individual animals (Hrycik et al., 2017; Townhill et al., 2016), and ultimately reduced productivity for affected populations.

Climate change will exacerbate hypoxia because warming reduces the solubility of oxygen, increases biological oxygen consumption, and reduces ventilation in the world's oceans, which increases residence time of deep water. Increased residence time means that fishes, invertebrates and bacteria have more time to remove oxygen through respiration, and deoxygenation becomes more pronounced (Breitburg et al., 2018). Modelling analysis of the impacts of increasing temperature and hypoxia in the Gulf of St. Lawrence indicates significant declines in biomass production (*see* Case Story 7.4).

Case Story 7.4: Vulnerability of Greenland halibut in the Gulf of St. Lawrence

Greenland halibut inhabiting the Gulf of St. Lawrence is the warmest water population of this cold-water species. The population faces chronic hypoxia over its entire distribution, with oxygen levels at less than 50% of saturation. Hypoxia is most severe (18–25% saturation) at the head of the main channels, including the St. Lawrence Estuary, which is the main nursery for this population. Both laboratory studies (Dupont-Prinet et al., 2013) and field sampling (Youcef et al., 2015) show that low oxygen levels reduce the feeding and growth rates of juvenile Greenland halibut. A distribution model based on environmental conditions and abundance predicts a reduction in the distribution and abundance of this species in the Gulf of St. Lawrence by mid-century (2046–2065) (*see* Figure 7.6; Stortini et al., 2017).

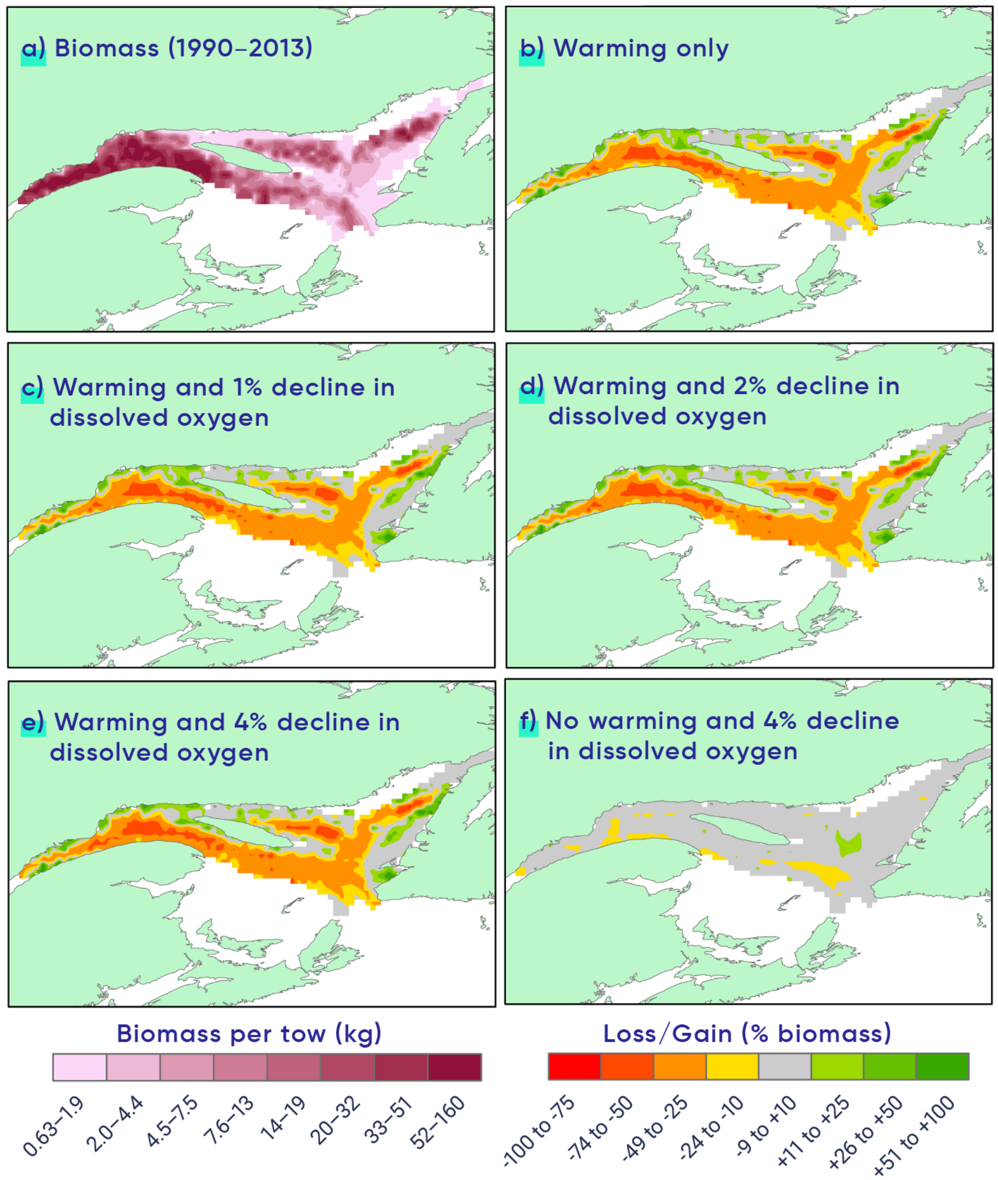


Figure 7.6: Results of five simulations for the distribution and abundance of Greenland halibut in the Gulf of St. Lawrence. a) Actual biomass data for the period 1990–2013. b) Scenario involving warming only. The scenarios shown in panels c), d) and e) involve the same level of warming as in panel b), but this warming is accompanied by different levels of oxygen decline (c = 1% decline, d = 2% decline, and e = 4% decline). f) Scenario with a 4% oxygen decline and no warming. The impacts of warming alone (b) and warming accompanied by a 4% saturation decline in dissolved oxygen (e) appear similar with the colour coding used, although warming alone reduced high-density areas by 49%, whereas the two stressors combined caused a 57% reduction. Decline in dissolved oxygen without the increase in temperature only reduced biomass by 2%. Source: Adapted from Stortini et al., 2017.

7.3.4 Acidification

Ocean acidification is caused by higher concentrations of CO_2 in the air, increasing the dissolution of CO_2 in the oceans to create carbonic acid and exceeding the ocean's ability to buffer against the increase in acid concentration. One measure of acidity is pH, with lower values representing a higher level of acidity. Since the Industrial Revolution, ocean pH has declined globally on average by 0.1 pH units, representing an increase of 26% in the number of hydrogen ions, and is predicted to further decrease by 0.4 pH units by 2100 under a high-emissions scenario (RCP8.5) (Ciais et al., 2013). Many studies have shown that the important commercial species of fish, shellfish, crustaceans and gastropods can suffer negative effects when exposed to acidified water (Alin et al., 2019; Parker et al., 2013; Kroeker et al., 2010). Ocean acidification has already had a massive impact on shellfish, where changes in seawater carbonate chemistry alter the ways in which juvenile (larval) shellfish build their shells, and can cause shell dissolution, deformities, slow growth and even death (Waldbusser et al., 2015; Gazeau et al., 2013). Ocean acidification impacts on shellfish aquaculture are evident through clear linkages between high CO_2 seawater concentrations and poor larval development of Pacific oysters in the United States shellfish industry (Barton et al., 2012). Shellfish hatcheries generating juvenile oysters for field outplanting were severely affected, with losses of money and jobs (Ekstrom et al., 2015). In the Atlantic, research is underway to examine the impacts of ocean acidification on the commercially valuable American lobster (*see* Case Story 7.5).

Case Story 7.5: Lobster production in Atlantic Canada impacted by ocean acidification

Lobster is the most lucrative fishery in Atlantic Canada. Key lobster production areas in the Gulf of Maine, Bay of Fundy and Scotian shelf are highly susceptible to ocean acidification due to poor regional buffering capacity and coastal nutrient inputs (Gledhill et al., 2015). Ocean acidification studies on both the early larval phases (stages I–IV) (Keppel et al., 2012) and early benthic phase juveniles (McLean et al., 2018) found slowed growth and an increased time between moults in more acidified seawater conditions. Low pH can also cause deformities in lobster larvae (*see* Figure 7.7). When lobsters are smaller and when they remain in the pelagic phase for longer periods, there is an increased likelihood of predation, therefore potentially limiting benthic recruitment (Keppel et al., 2012). Delayed growth of benthic juveniles also increases predation susceptibility (McLean et al., 2018), and ultimately affects population dynamics. Juvenile benthic lobsters in acidified conditions are also more susceptible to shell disease (McLean et al., 2018).

Figure 7.7: Healthy stage IV American lobster reared in ambient conditions (bottom) and a deformed stage IV lobster larvae under acidified conditions (top). The acidified lobster is smaller and claws have been lost due to environmental stress. Photos from a recent study at the St. Andrews Biological Station, Fisheries and Oceans Canada.

Warming will also influence lobster populations in other parts of eastern Canada. Larvae are particularly sensitive to warming (Waller et al., 2017). Settled lobsters are more tolerant of warming, which is projected to have a neutral or positive impact on lobster in the offshore areas of the Scotian Shelf (Greenan et al., 2019b). This is likely to be the case off Newfoundland and in the Gulf of St. Lawrence as well, except in some parts of Northumberland Strait where temperatures can exceed 23.5°C, a level that is avoided by lobster (Wilson and Swanson, 2005; Crossin et al., 1998). Furthermore, management adaptation is possible; protection of large individuals has been suggested as an adaption strategy for reducing the impact of warming (Le Bris et al., 2018).

7.3.5 Moving forward

Fish stocks are assessed using the best available evidence, produced through basic research and using research monitoring programs. The resulting data are used to create physical forecast models that enable a longer-term understanding of climate change. The known associations between species abundance and environmental variables can be used to assess species vulnerability to warming (Stortini et al., 2015), to project future available habitat, and to facilitate planned adaptation to changes in distribution and productivity (Stortini et al., 2017; Marras et al., 2015; Shackell et al., 2014).

Fisheries management combines scientific advice with social and economic information to make decisions about the fishery. Canada has initiated a process to incorporate climate change into science advice on fisheries, with initial emphasis on the stock assessment process as part of ecosystem-based management (Fisheries and Oceans Canada, 2018e). Commercial stocks are assessed and managed within stock area units, with borders separating distinct stocks. Climate change adds another layer of complexity to the assessment and management process, in that we anticipate changes in distribution/productivity within and across borders. Increased understanding of the impact of multiple stressors on fishes and aquatic invertebrates will make it possible to develop more realistic models of the future abundance and distribution of commercial species, providing a stronger scientific foundation for resource management strategies.

7.4 Climate change brings benefits and threats to the agriculture sector

Climate change brings both opportunities and challenges to Canada's agricultural sector. Longer growing seasons and the potential to grow crops farther north may benefit agriculture, while changes in water availability, extreme weather events, and pests and diseases will present challenges. Adaptation actions that enhance climate resilience and consider the linkages between agriculture and interconnected sectors, such as water management and transportation, will benefit both local sustainability and global food security.

Agriculture is inherently sensitive to climate. Increasing temperatures, shifting precipitation patterns, and changes in the frequency and intensity of some extreme climate events will affect crops and livestock operations, by both amplifying existing risks, and bringing new risks and opportunities. The type and degree of impacts will vary across agricultural regions and production systems. For example, increasing abundance of insect and disease species, and greater risk of new pests and diseases will impact crop and livestock health and could increase the risk of trade barriers. Additional risks arise from the sector's strong dependence on transportation systems to maintain access to markets—systems that are themselves vulnerable to climate change impacts. Improvements to on-farm management practices—including improved fertilizer management, adoption of no-till practices to minimize soil disturbance, and improved water-use efficiency—have enhanced the sector's climate resilience and illustrate a high capacity to adapt.

7.4.1 Introduction

While Canada's agriculture sector is intrinsically adaptive (Campbell et al., 2014), its ability to adapt is being challenged by the impacts of climate change, including a northward shift in distribution of many insect and disease species and new invasive species. Changes in temperature and precipitation patterns, discussed comprehensively in Zhang et al. (2019), will bring shifts in the distribution of crops. Despite the fact that precipitation is projected to increase for Canada as a whole, areas such as the southern Prairies and the interior of British Columbia are expected to see increased moisture deficits during the growing season (Zhang et al., 2019), increasing the importance of irrigation and good water management.

Canadian agriculture is also highly dependent on reliable transportation networks to ensure that inputs (e.g., seed, fuel, fertilizer, pest control products and equipment) are delivered in an efficient, cost-effective and timely manner, and to maintain access to domestic and international markets. Flooding and other extreme weather events will challenge Canada's grain handling and transportation system (Phillips and Towns, 2017).

Improvements over the last twenty-five years have made Canada's agriculture sector more climate-resilient (*see* Prairie Provinces chapter; Campbell et al., 2014). There has been an increased focus on collaboration between producers, researchers, and decision makers within interconnected sectors to assess impacts and implement new adaptation measures, and this will contribute to increasing the sector's sustainability. This section examines recent developments in understanding climate change impacts on agriculture in Canada and the critical inter-connectivity between agriculture and transportation. A more in-depth discussion of agriculture at the regional level can be found in the regional chapters (*see* Atlantic Provinces, Ontario, Quebec, Prairie Provinces and British Columbia chapters).

7.4.2 Climate risks and regional adaptation planning

Understanding climate risks to agriculture is informed by inputting observed and projected climate data into agricultural models (e.g., for crops, livestock, pests and diseases) to identify potential physical and economic impacts. Planning and implementation are required at various scales to target and identify actions within whole agricultural value chains, to inform on-farm impacts and to identify appropriate adaptation actions.

Analysis of climate change impacts on agricultural production in Canada, summarized previously by Campbell et al. (2014), continues to improve. Under medium-emissions (RCP4.5) and high-emissions (RCP8.5) scenarios, production of wheat (Canada's largest crop and greatest value export) and other spring-seeded grains is projected to increase by between 8% and 11% by the 2050s (2041–2070), relative to a 2006–2015 baseline, across most of Canada's agricultural regions (Qian et al., 2019; He et al., 2018). Increased heat stress could reduce canola yields across the southern Prairies, which will likely lead to a northward shift in crop production areas (Qian et al., 2018). Climate impacts on corn and soybean production in Canada remain less conclusive, with some studies showing increased suitability in Atlantic and central Canada, and opportunity for expansion in the Prairies, provided moisture limitations are not too restrictive (*see* Prairie Provinces chapter; Agriculture and Agri-Food Canada, 2018; He et al., 2018; Schauberger et al., 2017; Sauchyn and Kulshreshtha, 2008).

Severe moisture deficits by the 2050s are projected for certain areas of Canada under a high-emissions scenario (*see* Figure 7.8), which will particularly affect spring-seeded grain crops, such as wheat and barley. Water scarcity would be amplified by increased demand for water by other sectors, especially where irrigation and access to water are already important constraints on the sustainability of agriculture. Climate change is projected to increase variability in water supply, and to strain irrigation, drainage and flood control systems. For example, glacial meltwater, which contributes approximately 10% of summer flow in the Columbia River and Bow River, will be reduced to almost zero over the next 50 to 60 years as glaciers disappear (Derksen et al., 2019; Fyfe et al., 2017). Glacial water melt is very important for maintaining summer flows in the rivers of western Canada, during the key growing period. Increasing irrigation and on-farm water-use efficiency is a key adaptation mechanism. Currently, irrigation is practiced on 1.1 million hectares of Canada's 44 million hectares of arable land (2.27%). While there is irrigation in every province, over 90% occurs in Saskatchewan, Alberta and British Columbia.

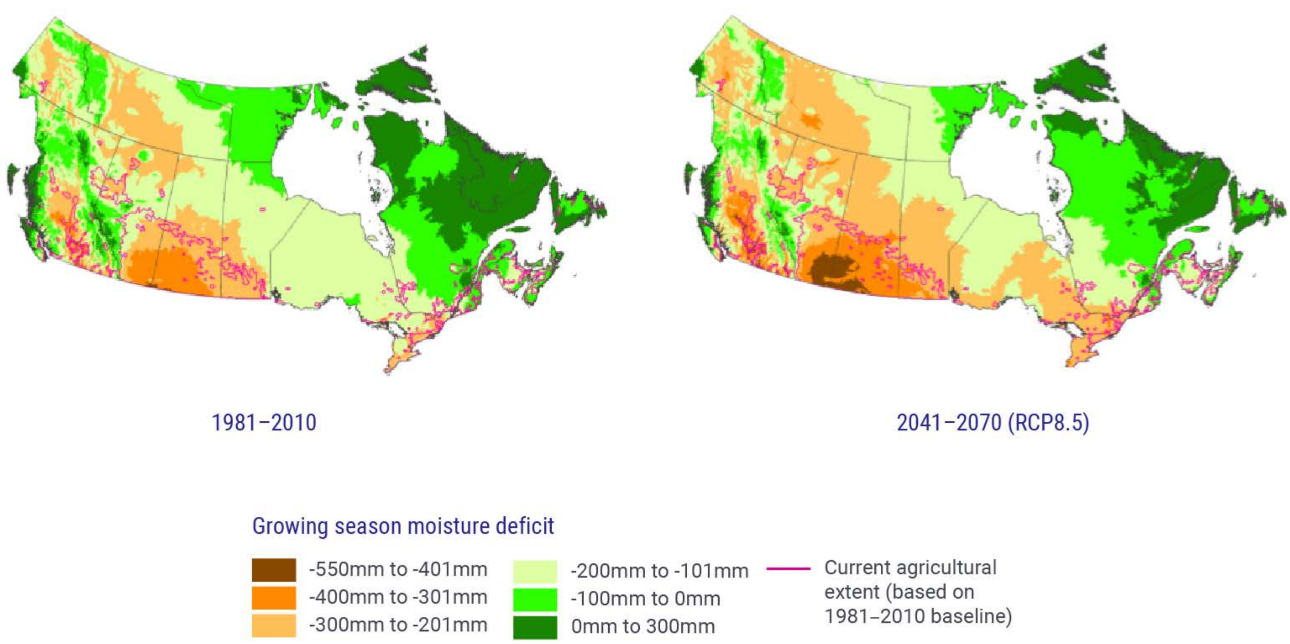


Figure 7.8: Growing season moisture deficit (precipitation minus potential evapotranspiration) across Canada for the period 1981–2010 and for the period 2041–2070 as projected under a high emissions (RCP8.5) scenario. In most areas, increased precipitation is more than offset by increased temperature and associated evaporation, leading to greater moisture deficits. Source: Agriculture and Agri-Food Canada, 2018.

The risks posed by animal diseases and plant pests are increasing as a result of climate change, with the likelihood of new invasive alien species (IAS) being introduced to Canada having significant consequences for Canada's agriculture sector and economy. It is estimated that invasive species currently cause $4.2 billion in annual measurable losses to Canada's agriculture industry (Agriculture and Agri-Food Canada and Canadian Food Inspection Agency, 2008). These relate to reduced crop yields and revenue, increased IAS control costs, loss of access to export or domestic markets, and decreased native biodiversity resulting from competition for resources.

Modelling of pest and disease expansion under a changing climate indicates that the ranges of the striped flea beetle, *Phyllotreta striolata* (*Fabricius*), and the crucifer flea beetle, *P. cruciferae*, both IAS to North America, are projected to shift and potentially cause economic losses over an expanded area in the future (Olfert et al., 2017). Increased winter temperatures have contributed to higher overwinter survival of insect pests (Olfert et al., 2016) and some pathogens, including cereal rusts in the Prairie region (Xi et al., 2015; Kumar et al., 2013). The linkage between climate change and the rapid north and westward range expansion of the deer tick (*Ixodes scapularis*), which transmits the Lyme disease agent that can infect cattle and other livestock, as well as humans, is well documented (Ogden et al., 2014). Bluetongue, a viral disease of ruminants transmitted by the biting midge *Culicoides sonorensis*, extends from the southwestern United States into southern British Columbia and Alberta (Lysyk and Dergousoff, 2014), and has recently expanded into southern Ontario (Jewiss-Gaines et al. 2017). Species distribution models based on different climate change scenarios indicate that the range of *C. sonorensis* is likely to expand northward in Alberta (Zuliani et al., 2015).

Barriers to adaptation across the agriculture sector broadly (*see* Figure 1 of Campbell et al., 2014) include a lack of knowledge of climate impacts, limited technical capacity to assess agricultural risks at an appropriate scale, and uncertainties associated with projected climate impacts and adaptation actions (Agriculture Adaptation Working Group, 2016). Recent efforts by the agriculture sector to assess climate risks and consider adaptation actions, both regionally and at the farm level, have started to address these barriers. Examples include developments in climate risk assessment methodology and agricultural adaptation planning in Quebec (Ouranos, 2015), Manitoba (Goertzen, 2018), Nova Scotia (Nova Scotia Federation of Agriculture, 2018) and British Columbia (British Columbia Ministry of Environment and Climate Change Strategy, 2019). Continued work could further improve understanding of risks, the agricultural sector's awareness of climate impacts, and mechanisms to support adaptation action. New knowledge will continue to inform initiatives such as the agriculture sector's Emergency Management Framework (Federal, Provincial and Territorial Emergency Management Framework Task Team, 2016), which includes elements to help proactively manage the increasing risk of pests and diseases and potential associated trade risk issues.

7.4.3 Inter-connectivity

The success of agricultural production in Canada is highly dependent upon connections with transportation networks. A reliable transportation network allows for efficient delivery of necessary input goods (such as seeds, fuel, fertilizers and farm equipment), as well as access to export markets. Climate change presents a wide range of risks to transportation networks in Canada (*see* Section 7.7; Palko and Lemmen, 2017), including damage to infrastructure from extreme precipitation and flooding, impacts associated with sea-level rise and storm surge flooding at terminal ports, increased risk of rail buckling due to extreme heat, cracking of roadways as a result of desiccation of clay sub-soils during drought conditions and washouts during flooding.

All of these impacts can cause transportation delays that negatively impact the agriculture sector value chain (e.g., farmers, processors, suppliers, etc.) from local to international scales.

Canada's grain handling and transportation system is frequently impacted by extreme weather events. For example, excessive rainfall in Vancouver between January and March 2011, and severe weather events in the railway mountain corridors of British Columbia contributed to long delays in loading grain onto vessels in Vancouver ports (Quorum Corporation, 2014). Again in 2013, record totals of harvested crops in the Prairie provinces, followed by extreme cold winter conditions, contributed to transportation delays in accessing markets. Such delays impact Canada's reputation as a reliable supplier of agricultural products and result in added costs for both grain companies and producers (Gray, 2015; Quorum Corporation, 2015).

The importance of export markets for the Canadian agricultural sector cannot be overstated, with approximately 42% of its annual production being shipped out of the country. In 2013, Canada was the world's fifth-largest exporter of agriculture and agri-food products (Agriculture and Agri-Food Canada, 2016), with exports representing 85% of canola and canola products, 85% of flax, 66% of soybeans and soybean products, 65% of hogs and pork products, and 48% of cattle and beef products. Over the past 10 years, half of all Canadian grain production has been exported, averaging 41 million tonnes per year. Agri-food export sales in 2017 totalled $57.7 billion (Canadian Agri-Food Trade Alliance, 2020). While regional climate change impacts on agriculture production in Canada will be significant, impacts are expected to be much greater in most other major agriculture producing areas of the world (Food and Agriculture Organization, 2017; Ignaciuk and Mason-D'Croz, 2014). This represents both an opportunity for Canadian producers (Ignaciuk and Mason-D'Croz, 2014) and a critical need with respect to global food security (Mbow, 2019).

7.4.4 Moving forward

Mechanisms that support regional capacity to utilize and interpret climate change impacts and adaptation information are improving the ability of the sector to proactively plan and implement adaptation actions. It is also increasingly important for the sector to collaborate with other appropriate sectors, including transportation and water management, on shared adaptation issues. Initiatives such as Drought Watch (Agriculture and Agri-Food Canada, 2019), which provides information on current climate risks and provides a mechanism for producers to submit details on impacts experienced at the farm level, are an important step forward in enhancing engagement and collaboration.

7.5 Climate change brings new environmental challenges for mining

Impacts on the chemical and physical stability of tailings containment and reclamation structures are among the greatest climate-related challenges to the Canadian mining industry. Failure of such structures can lead to severe environmental contamination and present risks for surrounding communities and ecosystems. Considering long-term climate change at the design phase of mining projects is necessary to reduce these risks.

Climate change can affect every phase of a mine's life cycle. While short-term challenges, such as impacts on daily operations and disruption of critical supply chains, require adaptive actions, impacts on tailings containment and reclamation structures represent key vulnerabilities for the Canadian mining industry. Tailings containment and reclamation structures must remain in place for many decades and even centuries, which increases their vulnerability to climate change. While current designs of such structures take into account both average and extreme historical conditions, this does not adequately capture the full range of likely future conditions. Adaptation priorities include incorporating climate change projections into future designs, enhancing monitoring of existing structures and developing new methods and tools to improve climate resilience.

7.5.1 Introduction

Mining is a major component of the Canadian economy, with activities occurring in all provinces and territories. The effects of climate change on the mining sector are both direct and indirect, with the potential to affect every phase of a mine's life cycle (Bussière et al., 2017; Pearce et al., 2011; Stratos, 2009). In many cases, climate change will exacerbate existing climate risks and create new risks, but it will also afford some new opportunities (Stratos, 2017, 2009; Bussière et al., 2017; Pearce et al., 2011). For example, during the exploration phase, the shorter period of frozen ground will make it difficult to access some exploration sites. On the other hand, a longer warm season will allow more time for mapping and the delivery of raw material supplies by ship or floatplane.

An overview of climate change impacts and adaptation in the Canadian mining sector by Lemmen et al. (2014) highlighted risks to built infrastructure, transportation, extraction and processing, and daily operations. The project phases most affected are the management of mine tailings during operations and the reclamation of waste storage areas. These two phases have a long life span, and climate considerations are incorporated into their design (Bussière et al., 2017). Lemmen et al. (2014) also noted a lack of proactive adaptation planning for climate change in the sector, a conclusion supported by subsequent analysis that found little evidence of government or corporate policies having advanced in terms of addressing climate change impacts and adaptation (Stratos, 2017).

This section builds on previous Canadian assessments by focusing on what has emerged as a key climate vulnerability for the Canadian mining industry—risks to the physical and chemical stability of structures designed to contain tailings during and following mining activities, and risk to the long-term effectiveness of reclamation methods (Bussière et al., 2017; Stratos, 2017).

7.5.2 Tailings containment structures

Mining waste, composed of finely crushed rock and water, is stored in tailings ponds that are generally located at surface-level close to the mine (Blight, 2010; Bussière, 2007; Bussière et al., 2005; Aubertin et al., 2002). The purpose of these ponds is to contain the greatest possible volume of solid waste and permit the transfer of any overflow into one or more secondary ponds (called sedimentation and/or polishing ponds). These structures are usually created by closing off a natural valley or cordoning off an existing area with one or more dykes. They are equipped with drainage systems to allow the water, once solids settle, to be reused or processed, with spillways to control effluence during periods of extreme precipitation (Blight, 2010; Aubertin et al., 2002). Given the high water content and low density of most mine tailings, the physical stability of these structures is difficult to maintain over both the short and long term. Structures are frequently modified throughout the extraction stage of a mine (generally a few decades) to adapt to evolving operating conditions.

Current approaches to designing tailings containment structures consider both average and extreme climate parameters, such as probable maximum precipitation (PMP) and probable maximum flood (PMF) (Aubertin et al., 2015). PMP and PMF are based on frequency analyses of historical climate data, and have a low annual probability of recurrence (Canadian Dam Association, 2013; Aubertin et al., 2011; Koutsoyiannis, 1999). The use of PMF is recommended in the conversion to permanent structures when a mine is closed, in order to avoid breaches and potential environmental, human and material consequences (Centre d'expertise hydrique du Québec, 2019; Canadian Dam Association, 2013; Ministère du Développement durable, de l'Environnement et des Parcs, 2012; Aubertin et al., 2002, 1997; Vick, 2001). Importantly, there is currently no uniform methodological approach to factor climate change into the PMP and PMF calculations.

The frequency and intensity of extreme precipitation events, as well as average annual precipitation levels, are projected to increase in most regions across Canada (Zhang et al., 2019), increasing the risk of physical instability of waste containment structures (Bussière et al., 2017; Guthrie et al., 2010; Jakob and Lambert, 2009). Recovering spilled waste resulting from a dyke breach is difficult and expensive. For example, the tailings pond failure at the Aznalcollar mine in Spain in 1998 led to site reclamation costs estimated at about US$230 million (Eriksson and Adamek, 2000). In northern Canada, increasing temperatures are leading to permafrost degradation and increased depth of the annual thaw (active layer) (Derksen et al., 2019; Arzhanov and Mokhov, 2013; Zhang et al., 2008a, b). As a result, the integrity and stability of waste-retaining structures may be compromised. Increased thickness of the active layer can create problems in locating suitable construction sites for mining infrastructure; it should be noted that technologies for building on permafrost do exist and that relevant guidelines are well documented (Mine Environment Neutral Drainage, 2012; Doré and Zubeck, 2009; Andersland and Ladanyi, 2003).

7.5.3 Reclamation of mining sites

Reclamation of mining sites includes preventing contaminants such as acid mine drainage (AMD) from escaping into the environment (Blowes et al., 2003). This is possible by maintaining the long-term chemical stability of mine waste, as AMD results from the oxidation of sulphide minerals when they come into contact with water and atmospheric oxygen. Specific reclamation methods for preventing AMD are strongly influenced by climate conditions (*see* Box 7.1 and Case Story 7.6).

Box 7.1: Primary reclamation methods used in Canada

Reclamation of mine waste sites in Canada often uses covers to prevent acid mine drainage (AMD) (*see* Figure 7.9). In semi-arid to arid climates, such as the southern Prairie provinces and parts of south-central British Columbia, where the potential evaporation rate is high and annual rainfall low, reclamation systems aim to reduce the infiltration of precipitation into mine tailings that could generate contaminated drainage. In humid climates, such as in Ontario and southern Quebec, where the potential evaporation rate is relatively low with high annual precipitation, there is the additional task of creating barriers to control the migration of oxygen. In Arctic and sub-Arctic climates with continuous permafrost, controlling contaminated mine drainage usually consists of maintaining reactive waste at low temperatures by applying insulating covers that utilize the material's hydrothermal properties (applicable for average annual temperatures below -7°C; Holubec, 2004). Some techniques used in more temperate climates (e.g., flooding, waterproof covers) can also be applied to control AMD in cold regions (*see* Figure 7.9; Aubertin et al., 2016, 2015).

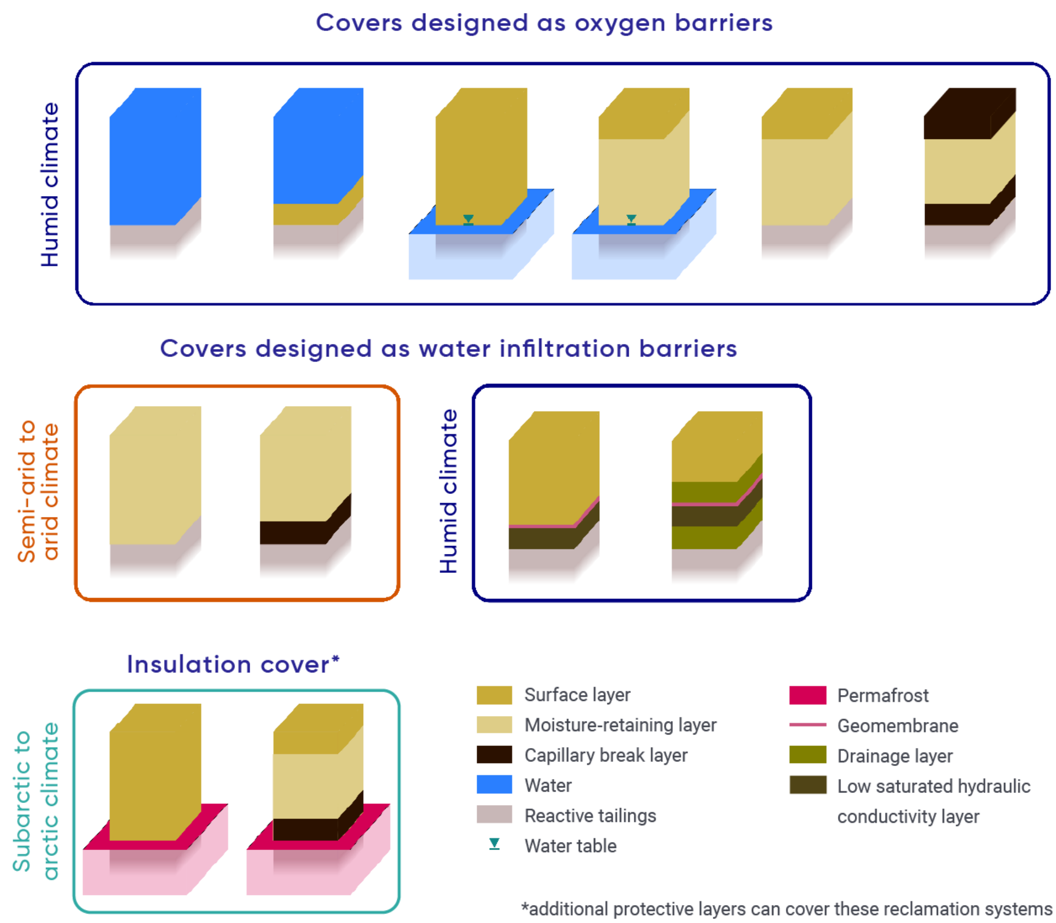


Figure 7.9: Primary reclamation methods used in Canada. Methods are designed to address critical issues that differ with climate regions. Source: Adapted from Bussière et al., 2017.

Case Story 7.6: Reclamation of the Lorraine, QC mine site

The Lorraine mine site in western Quebec was operational from 1964 to 1968. The tailings pond at this site covers an area of 15.5 hectares and was abandoned for about 30 years. During this period, significant acid mine drainage (AMD) was produced. To reduce the environmental impact of AMD, a reclamation project was undertaken in the summer of 1998 (Bussière et al., 2009; Nastev and Aubertin, 2000). Various issues were considered in selecting the most suitable design, including local climate, geochemical characteristics of the tailings, and available unconsolidated materials. The region receives significant annual precipitation (900–1,000 mm) and the evaporation rate is low (400–500 mm). In such a humid climate, controlling AMD generation focuses on reducing the migration of oxygen rather than using a water barrier (*see* Box 7.1). The reclamation approach recommended for this site was the construction of a cover with capillary barrier effects (CCBE) to limit the migration of oxygen into the reactive waste.

This site has been monitored since the CCBE construction. Measurements performed on the site show that after a transitional period of two years (1999–2000), the CCBE was effective in limiting oxygen migration (*see* Figure 7.10; Bussière et al., 2009; Dagenais et al., 2001). Oxygen fluxes measured are even lower than the goal targeted by the design. Numerical modelling incorporating climate change was carried out in order to assess recovery performance over the long term. The results show that, in this particular case, climate change will not have a significant impact on CCBE performance by 2100 (Hotton et al., 2019).

Figure 7.10: Evolution of the Lorraine, QC mine site reclaimed using a cover with capillary barrier effects. a) Before reclamation, b) after the 1998 reclamation and c) the site in 2007. Source: Adapted from Bussière et al., 2009.

The long-term effectiveness of reclamation systems is affected by many factors (Aubertin et al., 2015, 2002) related to the properties of the covering materials, the configuration and location of the containment area to be reclaimed, and climate. As the required life of reclamation structures is greater than 100 years, this is the stage of the mining cycle most likely to be severely impacted by climate change.

The main climate change risks during the reclamation of mining sites are reduced effectiveness of insulation covers, water infiltration barriers and oxygen barriers, and failure of retaining structures on sites undergoing reclamation (*see* Figure 7.11; Bussière et al., 2017; Lemmen et al., 2014). Direct climate change impacts of concern include: 1) higher temperatures that increase the depth of the active layer in sub-Arctic and Arctic regions, potentially resulting in the thaw of waste that could generate AMD; 2) an increase in extreme precipitation that could lead to the physical failure of dykes or other structures when employing reclamation methods such as water cover and elevated water table techniques; and 3) longer or more frequent droughts that could compromise the effectiveness of oxygen barriers that need high levels of saturation in the tailings and/or covers. Indirect climate change impacts, such as vegetation changes on revegetated sites affecting the water balance and the properties of the covering materials, can also positively or negatively impact the effectiveness of reclamation in both the short and long terms (Guittonny et al., 2018; Reinecke and Brodie, 2012).

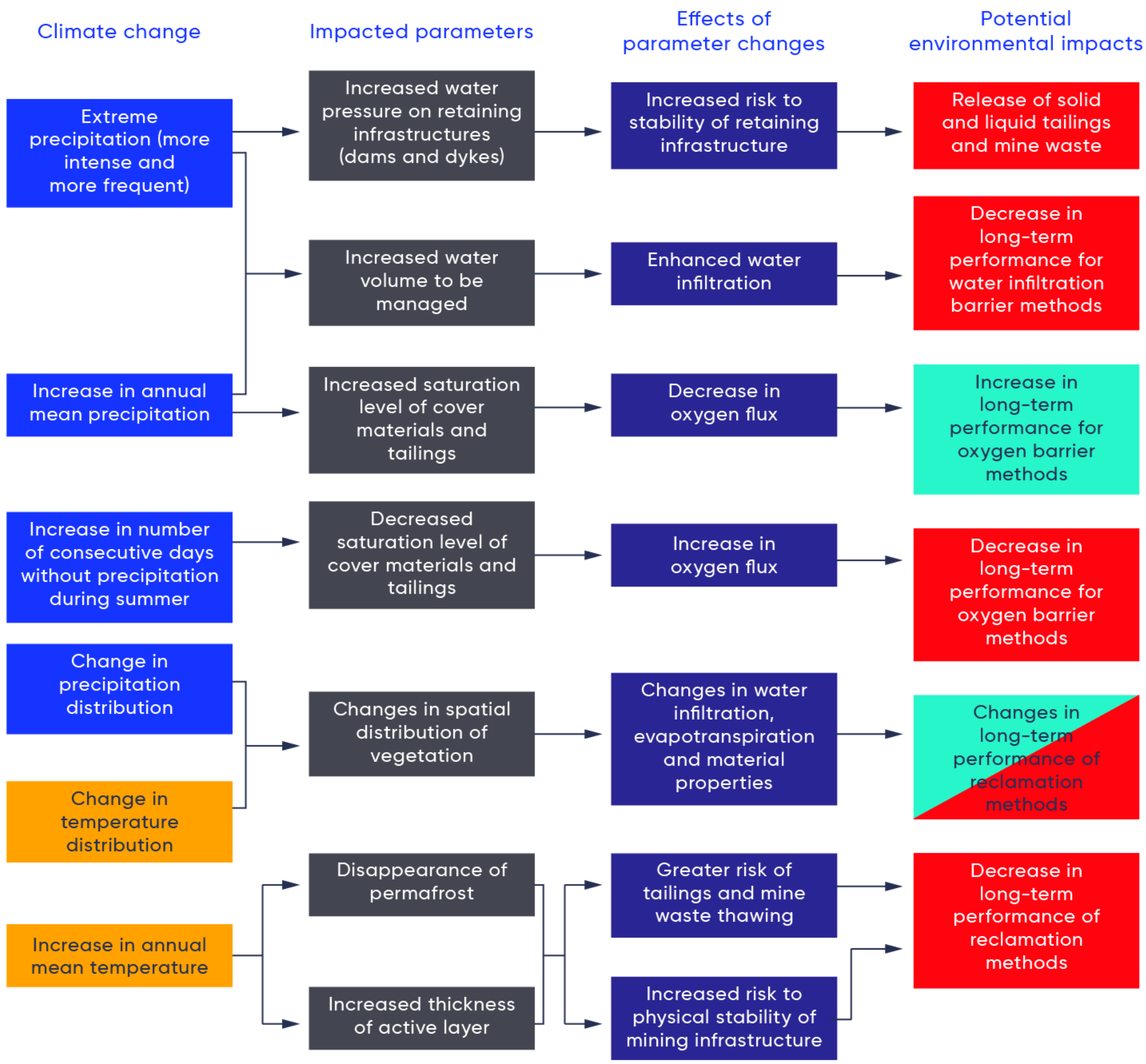


Figure 7.11: Summary of expected major climate changes and their implications for mine waste containment and reclamation structures.

7.5.4 Adaptation

Maintaining the stability of tailing containment structures currently represents a major challenge for the mining industry when following conventional containment methods (Aubertin et al., 2011; Azam and Li, 2010). Climate change will amplify these risks. Adaptation will involve considering approaches that reduce reliance on dykes to retain large volumes of water and tailings pulp. Thickened or filter-pressed tailings may be one viable option (Bussière, 2007). Co-disposal approaches of waste rock and tailings could also improve the mechanical resistance of containment structures for mine tailings (Aubertin et al., 2016, 2011; Wilson et al., 2003). The reuse of mine openings (open pits or underground voids) for the storage of waste rock and tailings can also help to reduce the problems of dyke instability (Aubertin et al., 2016, 2015). If mining companies choose to use conventional methods for mine waste storage, the effects of climate change must be integrated into risk management analysis during the design stage. Approaches with this aim are being developed in conjunction with the Mining Association of Canada and the Canadian Dam Association.

While most governments now require proof that climate change has been considered in the design of any reclamation project (e.g., Ministère du Développement durable, de l'Environnement et des Parcs, 2012 for Quebec), the lack of specific guidance on how to modify reclamation methods in the context of climate change remains a barrier to effective adaptation.

Specific tools and analysis are needed: for example, to inform the design of oxygen barriers, where an extended drought could lead to desaturation of the cover, increasing oxygen ingress (Bresson et al., 2018; Hotton et al., 2018). While studies in Quebec have simulated a period of approximately two months with no water intake (Éthier et al., 2018; Bussière et al., 2003), the choice of this period of time was not based on systematic analysis of meteorological data, and the probability of such an event occurring is unknown. Tools are needed that quantify the changing risk of extreme drought to be considered in the design of oxygen barriers. For sites located in cold climates, where increasing temperatures and precipitation will have a major impact on the performance of reclamation methods, the need for adaptation planning tools is particularly urgent.

Enhanced understanding of local impacts is also needed to inform the planting of perennial vegetation at reclamation sites. Over time, ecosystem changes driven by changing climate will result in species changes at the sites, but the impacts on the long-term effectiveness of reclamation systems are largely unknown (Guittonny et al., 2018). Monitoring the performance of such sites, to document whether such changes lead to deterioration or enhancement of the reclamation system, would provide important insights.

7.5.5 Moving forward

New approaches and tools that factor climate change into the planning, design, and risk management processes of mining activities provide a sound basis for the mining industry and governments to reduce the sector's vulnerability to climate change. While numerous studies have recommended that climate change be taken into account in mine waste management (e.g., Rousseau et al., 2014; Stratz and Hossain, 2014; Pearce et al., 2009; Aubertin et al., 2002), uncertainty in projecting changes, particularly extreme precipitation events (Mailhot et al., 2014), remains a barrier to action. Solutions require collaboration between mining engineers and climate services in developing updated or new methods and guidelines for assessing climate impacts that can be factored into the design of tailings containment structures and reclamation methods.

The longevity of tailings containment and reclamation structures increases their vulnerability to climate change. The physical and chemical stability of such structures is essential to avoid release of harmful contaminants into the environment. Tools and guidance are required to better enable designers to accommodate both changes in extreme weather caused by climate change, and slow-onset changes such as permafrost degradation, and to develop climate-resilient reclamation methods. In some cases, it is possible that, for a given site, a “best” solution for current climate conditions may not be the optimum solution for future conditions. Better designed tailings containment and reclamation structures at active and closed mine sites can significantly reduce the risk of environmental contamination over the long term. In the case of older infrastructure, it would be advisable to conduct analyses to ensure that these facilities will be able to withstand future conditions. If not, remedial measures will have to be implemented to maintain the integrity of the structures over the long term.

7.6 Each link of the energy value chain can be vulnerable to climate change

Changing climate affects energy demand and the full energy value chain, from exploration and production through to transmission and distribution. Climate risks can be integrated into current business planning by considering co-benefits, no-regret options and incremental approaches. Climate resilience needs to be a key consideration in converting to low-carbon energy systems.

Warming climate increases the demand for cooling in summer and decreases the demand for heating in winter. Energy supply is sensitive to a wide range of climate impacts, including changes in permafrost, ice cover, sea level, wave regimes, precipitation patterns, river flows and extreme weather events, such as hurricanes and ice storms. These impacts can all disrupt the energy value chain, with significant economic and social consequences. The use of climate risk screening tools can help to embed adaptation within current business planning practices and to identify opportunities for introducing adaptation measures at cost-effective times (e.g., during maintenance, upgrades and retrofits). As significant investments are made to convert to low-carbon energy systems over the next few decades, it will be important to ensure that climate resilience is considered in infrastructure design.

7.6.1 Introduction

Energy is an important component of the Canadian economy, accounting for almost 10% of gross domestic product (GDP). Energy systems are the backbone of critical services, such as transportation, communication, health systems, drinking water and wastewater, as well as businesses and households. As such, their reliability is of paramount importance to economic activity and human well-being in Canada. Energy assets and operations have always been exposed to highly variable and extreme climate conditions, and were built to perform well under these conditions. Nonetheless, they were designed based on historical climate norms, which raises concern about their resilience in the face of ongoing changes in climate. Observed and projected climate changes that significantly affect the energy sector are described in Bush and Lemmen (2019), including changes in temperature and precipitation extremes (Zhang et al., 2019), permafrost, snow and sea ice (Derksen et al., 2019), streamflow (Bonsal et al., 2019) and ocean climate (Greenan et al., 2019a). Energy sector vulnerabilities to climate are highlighted by recent extreme events, including the 2016 Fort McMurray (Horse River) wildfire that devastated the community and caused substantial reductions in oil sands production, with an estimated loss of approximately 47 million barrels, costing producers 1.4 billion dollars in lost revenues (*see* Case Study 7.1; National Energy Board, 2016; Antunes et al., 2016).

Climate change also has direct and indirect impacts on energy demand. Warmer winters reduce fossil fuel and electricity demand for heating (Mantle314, 2019), while the increasing number of hot days in summer increase electricity demand for cooling (Ortiz et al., 2018; Jaglom et al., 2014). Indirect impacts are associated with societal and government responses to reduce greenhouse gas emissions, and these responses have differing impacts on renewable and non-renewable energy sources (International Energy Agency, 2016a).

Previous assessments of climate change impacts and adaptation highlight the diversity of the Canadian energy sector, noting that most available research focuses on hydroelectricity generation and electricity distribution (Lemmen et al., 2014). Key risks identified include impacts of extreme weather on critical infrastructure, and a potential mismatch between reduced hydroelectricity production and increased electricity demand during heat waves. Smart grid technologies and urban design measures that reduce heat island effects were noted as examples of adaptation measures (Lemmen et al., 2014). Knowledge gaps identified included the limited amount of research on the impacts of climate change on renewable energy supplies other than hydroelectricity. Environmental assessment and risk disclosure were identified as emerging drivers of adaptation action in the sector (*see* Climate Disclosure, Litigation and Finance chapter; Lemmen et al., 2014).

7.6.2 Risks to energy production and transmission

The impacts of a changing climate will vary between energy type and region, and may occur at different time horizons. The Canadian oil and gas sector fuels most transportation and accounts for 10% of Canada's electricity generation (Natural Resources Canada, 2018). Oil and gas exploration, extraction, production and delivery will be affected by climate change (Mantle314, 2019; Cruz and Krausmann, 2013). Pipelines, roads and buildings are affected by permafrost degradation, slope failures and flooding. In northern regions, thawing permafrost and reduced availability of stable ice roads affect transportation and require changes in schedules. River ice breakup will happen earlier in the year and ice jam flooding may occur more frequently. Sea-level rise will change flood risks and increase coastal erosion. A large water demand for energy production, including for oil sands, may pose a risk as overall water availability declines in some areas and droughts may intensify (Bonsal et al., 2019). Offshore activities may benefit from increased access to resources in the Arctic due to reduced sea ice, but will still face significant risks from ice in northern regions and increased impacts from waves elsewhere (Mantle314, 2019; Stantec Consulting Ltd., 2012). While not directly related to production, carbon capture and storage (CCS) technology is critical to the oil and gas sector's transformation to low-carbon systems. Indeed, the World Energy Council stated that "global warming is unlikely to be kept under 2°C without introduction and widespread adoption of CCS, and the cost of mitigation would be higher in the absence of CCS" (World Energy Council et al., 2014, p. 12). However, CCS technologies are water-intensive, using almost double the volume of water compared to non-carbon capture and storage plants, making them vulnerable to climate-related changes in fresh water availability (International Energy Agency, 2015).

Nuclear and fossil fuel thermal generation facilities depend on sufficient cooling water and may face reduced cooling efficiency due to higher water temperatures or contamination of cooling water intake (e.g., from algae, zebra mussels or ice particles during freeze/thaw cycles) (Braun and Fournier, 2016; Canadian Electricity Association, 2016). Maintenance schedules for nuclear facilities may be impacted by increased ambient temperatures, as temperature affects the number of workers allowed in vaults. Extreme impacts are exemplified by the shutdown of nuclear power plants in France due to lack of cooling water during the 2003 heat wave (Kopytko and Perkins, 2011).

Hydropower accounts for 59% of Canada's electricity generation (Natural Resources Canada, 2018). As this is a renewable energy source depending directly on climate conditions, hydropower production is impacted by changes in temperature, precipitation and snow cover. Shorter winters will result in earlier spring floods with a smaller contribution from melting snow. Winter flows are expected to be higher, and late summer flows may be reduced in many parts of Canada (Bonsal et al., 2019). At higher latitudes, where higher precipitation is not offset by increased evapotranspiration, generation potential may increase. However, with changes in rainfall frequency and intensity, risks to infrastructure may also increase and changes to water management would be needed to minimize losses. The high flexibility provided by the storage capacity of hydropower operations means that they can play a key role in transitioning to a low-carbon energy system, providing stability for electricity grids that integrate more volatile renewables such as wind and solar (International Energy Agency, 2018). A review of 200 projects in the energy sector suggests that hydropower is the most advanced subsector with respect to climate change adaptation (Braun and Fournier, 2016).

Non-hydro renewable energy, which includes wind, solar and biomass, is becoming increasingly important in Canada's energy mix, a trend that will continue in the future (*see* Figure 7.12; National Energy Board, 2018, 2017). Wind generation will generally be reduced from lower density air at higher temperatures. A 5°C increase in air temperature leads to a decrease in air density of 1–2%, with a proportionate decline in energy density affecting power production (Pryor and Barthelmie, 2010). However, wind generation may benefit from more sustained and higher winds. Fast market growth of renewable wind power (*see* Figure 7.12) reflects the influence of a larger share of renewable energy sources being integrated into the economy in response to climate change. Solar capacity is increasing even more rapidly than wind, and is expected to triple by 2040 (*see* Figure 7.12; National Energy Board, 2018, 2017). While there are concerns that an increase in cloudiness due to changing weather patterns and extreme weather events could affect solar energy generation (World Energy Council et al., 2014), the significance of these impacts is regionally dependent. More research is needed in Canada.

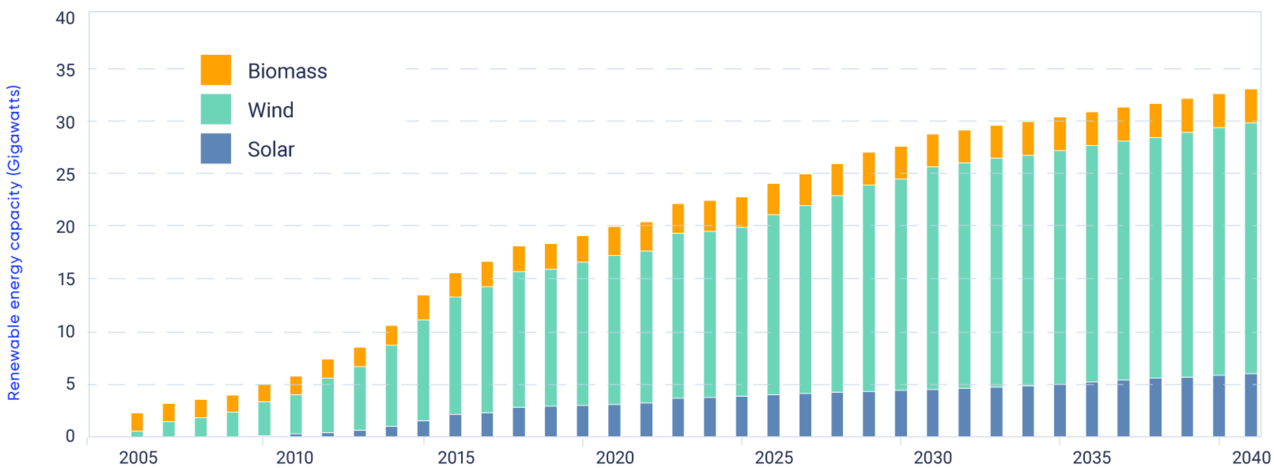


Figure 7.12: Observed and projected changes in non-hydro renewable energy capacity in Canada between 2005 and 2040 under the National Energy Board reference case scenario. Higher rates of growth are projected under a technology scenario (NEB, 2018). Source: Adapted from National Energy Board, 2018.

The electricity transmission and distribution sector will be affected by many factors, including the following: 1) increased temperatures, which can increase line resistance by approximately 0.4% per 1°C rise and decrease line load capacity by 0.5 to 1% per 1°C rise; 2) thermal expansion of power lines, which affects safety line clearances (a 1°C rise can result in 4.5 cm of sag); 3) extreme precipitation events that increase the risk of flooding of underground assets; and 4) high winds and gusts that can cause line damage (Asian Development Bank, 2013, 2012).

7.6.3 Adaptation

There are several examples of the energy industry adapting to changing climate conditions in Canada and around the world. Western Power Distribution in the UK studied the impact of higher ambient temperatures on its grid and developed a "low-regret" approach to adapt to an increase of their line rating by 5°C. To compensate for projected increased sag of the lines, they have started to gradually replace the poles in the course of normal maintenance (Western Power Distribution, 2011). Hydro-Québec has adopted a method to improve its energy demand forecasting by applying a climate-model derived adjustment factor to the historical temperature record prior to running the forecast model (Braun, 2016). A similar approach to improve flow forecasts has been adopted by Iceland's National Power provider Landsvirkjun, which has adjusted its streamflow record based on climate projections (*see* Case Story 7.7; Fournier, 2016).

Case Story 7.7: Opportunities for increased hydropower production in Iceland

Electricity and heating in Iceland are derived entirely from renewable sources (hydro and geothermal). Warming temperatures and increased precipitation result in increased glacier melt, runoff and generation capacity. However, the design of the current system in Iceland will only be capable of utilizing 30% of the projected additional runoff. Maximizing the opportunities presented by climate change will require new investments to increase storage in the system (*see* Figure 7.13; Sveinsson, 2015). Similar planning approaches may be appropriate in northern Canada where runoff is projected to increase as a result of climate change (Bonsal et al., 2019).

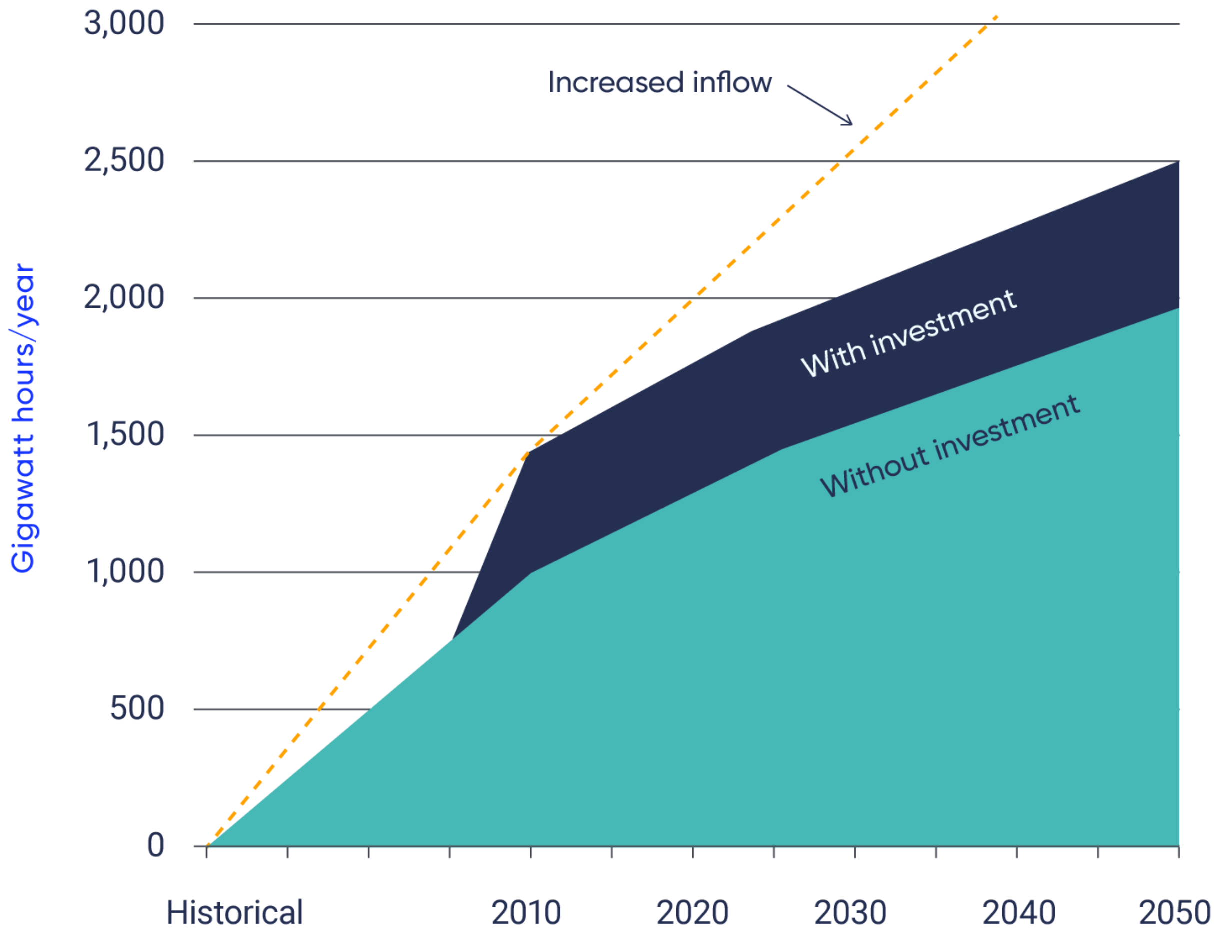


Figure 7.13: Potential increases in hydropower production in Iceland as a result of climate-induced increases in runoff and additional investments in infrastructure. Source: Adapted from Sveinsson, 2015.

New technologies are a key tool for climate change adaptation in the energy sector. The International Energy Agency's Sixth Forum on the Climate-Energy Security Nexus identified "technology innovation" as a priority area to advance energy sector resilience to climate change in North America (International Energy Agency, 2016b). While decentralized renewable energy technologies have been driven largely by demand for low-emitting energy sources, they also provide redundancy that can create sub-systems for generating and distributing energy in the event that other parts of the grid are disrupted (American Council on Renewable Energy, 2018; IISD, 2017; U.S. Department of Energy, 2016; International Energy Agency, 2015). Smart grid technologies, including renewable energy generation, smart meters, smart appliances, and automatic power production have been proven to improve recovery from extreme weather, such as in the US with Hurricane Irene (2011) and Hurricane Sandy (2012) (IISD, 2017; Executive Office of the President, 2013). For thermal generation, new dry-cooling technologies are being implemented to reduce the vulnerability to changing temperatures and diminish dependency on cooling water sources (Braun and Fournier, 2016).

7.6.4 Moving forward

Increased awareness is a critical first step in developing a climate-resilient energy sector that can ensure future energy security and reliable service for Canadians. Detailed case studies of projected impacts and actual or proposed business responses are a valuable tool for building such awareness (Braun and Fournier, 2016). Responses should be feasible, economically sound, and able to be implemented in adequate time frames. Cost-effective and beneficial responses can be built into existing business operations—for example, by addressing climate change as an integral part of environmental impact assessments, as is required for projects undergoing a federal impact assessment (Environment and Climate Change Canada, 2020).

Proactive energy providers in Canada and abroad have established in-house climate expertise and climate change committees. These committees collaborate with researchers and climate change centres to understand, produce and use climate data for establishing operational thresholds that are sensitive to climate. Engaging asset managers can be an important component of a holistic, integrated risk-based approach for energy planning, as is strong monitoring and evaluation. Sharing adaptation case studies between companies is another way to advance climate resilience in the energy sector.

7.7 Extreme weather events impact transportation, disrupting supply chains

Road, rail, marine and air transportation in Canada are vulnerable to extreme weather events and slow-onset climate change, with major disruptions having significant economic and social impacts. To fully assess these impacts, linkages between transportation systems, and between transportation modes and a wide range of other economic sectors, need to be accounted for. Coordinating adaptation responses across jurisdictions and sectors will benefit transportation asset owners, operators and those dependent on vulnerable supply chains and corridors.

Canada relies on efficient, safe and reliable transportation infrastructure and operations that enable the movement of goods, services and people across the country. Current climate risk assessment and adaptation initiatives in the transportation sector tend to focus on individual, direct climate impacts associated with air, road, rail or marine infrastructure and other assets. This approach underestimates the potential cascading risks and impacts from surrounding assets or networks, and vice versa. Examining how various elements of transportation are dependent upon each other, and how transportation is linked to a wide range of other sectors, can help to identify opportunities for collaboration and cost efficiencies, and can prevent situations in which actions taken to reduce individual or specific risks inadvertently increase the climate vulnerability of others.

7.7.1 Introduction

A well-functioning transportation sector connects people and communities, products, resources and services to domestic and international markets (Palko, 2017). In Canada, responsibilities for transportation are dispersed across various levels of government, with private-sector stakeholders playing an important role as owners, operators and managers of infrastructure and assets, including railway infrastructure, vehicles, ships and aircraft (Andrey and Palko, 2017). Canada's transportation infrastructure is concentrated mainly in the southern portion of the country, where most of the trade and transportation movements occur (*see* Figure 7.14). However, northern transportation systems are particularly sensitive to climate change, and are already impacted by thawing permafrost, reduced river, lake and sea ice cover, and increases in coastal erosion and storm surge flooding (Palko, 2017; Hori et al., 2017).

National Airport System

National Highway System

Canada Port Authorities

National Railway Network

Figure 7.14: Maps of Canada's national transportation systems, showing the National Airport System, the National Highway System, Canada Port Authorities and the National Railway Network. Source: Adapted from Transport Canada, 2017.

A comprehensive, regional-based report of climate change impacts and adaptation actions in Canada was released in 2017 (Palko and Lemmen, 2017). Key findings include:

- Canada's transportation infrastructure is vulnerable to damage and disruptions from a changing climate and extreme weather, and this can pose risks to other sectors of the economy;
- Northern transportation systems are experiencing some of the greatest impacts from warming, and temperatures in the North will continue to increase at a faster rate than in any other region of Canada; and
- While reactive approaches to managing climate risks remain common in Canada's transportation sector, there are examples from all regions and transportation modes of adaptation actions being taken in anticipation of future climate conditions.

This section supplements the report, *Climate Risks and Adaptation Practices for the Canadian Transportation Sector* (2017), by examining the interconnections that exist within intermodal transportation systems and across a wide range of sectors. It draws upon Canadian and international literature, and focuses primarily on physical infrastructure.

7.7.2 Climate impacts on transportation systems

Impacts of extreme weather events and climate change are already affecting transportation infrastructure, operations, systems and services across all modes in all regions of Canada (Palko, 2017); it should be noted that climate change has already increased the likelihood of some types of extreme weather events (Zhang et al., 2019). In some cases, these impacts have resulted in travel disruptions and unsafe conditions, affecting the movement of both freight and people, and leading to increased operating costs, reduced revenues or compensation for service disruptions.

Extreme weather events can incur large costs and accelerate the deterioration of transportation infrastructure, shortening its lifespan (Boyle et al., 2013). For example, a torrential downpour in Toronto in 2013 resulted in flooding that caused road closures, flight delays and cancellations, and stranded 1,400 train commuters. Damages were estimated to be $999.5 million (Amec Foster Wheeler Environment Infrastructure, 2017). That same year, flooding in southern Alberta caused $6 billion in damages, washing out 1,000 km of roads and destroying several hundred bridges and culverts (Andrey and Palko, 2017). In 2017 and 2018, the Churchill rail line was closed for 18 months (CTV, 2018) due to the cumulative effects of flooding and permafrost degradation beneath the railway line. Without a viable alternative mode of transportation to bring supplies in and ship goods out, living expenses escalated and access to essential services, including medical services located in southern communities, were compromised (Globe and Mail, 2018).

7.7.3 Understanding interdependencies

Infrastructure sectors and systems, including transportation, energy, telecommunications, water supply, wastewater treatment, solid waste management, and buildings, are "highly interdependent on each other, containing multiple connections, feedback and feed-forward paths and intricate branching" (Sudhalkar et al., 2017, p. 3).

Examples of critical interdependencies in transportation systems include situations where two sectors are essential to one another (e.g., transportation and energy), and where technology serves to strengthen connections between infrastructure, such as railway signals and traffic control systems being controlled by computer systems that depend on electrical power grids (Sudhalkar et al., 2017). Infrastructure networks containing one or more of these features "are at a higher risk of failure from external shocks or stresses, including climate hazards" (Sudhalkar et al., 2017, p. 3). Climate change risk assessments that do not address such interconnections could lead to the miscalculation of risks (Dawson, 2015).

Within the Canadian transportation sector, transportation modes (e.g., rail, marine, aviation and trucking) are often interconnected (intermodal) within supply chains and across transportation gateways and corridors. Port infrastructure and facilities, for example, form a central hub for transportation, logistics and supply chains, and are key convergence points for marine, rail and road infrastructure to facilitate movements of domestic and foreign goods (Becker et al., 2018).

Disruptions and delays in domestic and international supply chains, including those caused by weather events, can spread across networks with negative social and economic impacts (Becker et al., 2018; Allen et al., 2016; Zorn et al., 2016). In this way, vulnerabilities in one mode of transportation or sector can cascade to others.

7.7.4 Adaptation

Transportation asset owners and operators across Canada are undertaking actions to consider their climate risks and strengthen resiliency, often independently (Kwiatkowski, 2017). The distinct mandates, priorities, commercial sensitivities and resources of the many players within the sector create governance challenges and barriers to action (Sudhalkar et al., 2017). In the absence of holistic adaptation strategies, individual investments to address adaptation will be limited in effectiveness and could have unexpected and unintended negative consequences on neighbouring or interdependent assets and systems (Kwiatkowski, 2017). For example, the City of Toronto undertook a high-level climate risk assessment and interdependencies exercise for critical infrastructure and found that stakeholders had insufficient knowledge about the impacts of their activities on other interdependent systems, and that there was a need to implement roles and responsibilities to tackle joint risks (Sudhalkar et al., 2017).

Challenges for adaptation arise from many sources, including the fact that many transportation assets have long life-cycles, requiring lengthy planning and design, whereas technological development and replacement in areas such as information and communication technologies occur very quickly, leading to mismatched planning horizons and potential timing challenges (Man, 2013; Dewar and Wachs, 2008; Finley and Schuchard, nd). Opportunities arise when transportation planning is able to overcome such challenges and facilitate broad collaboration and engagement across sectors and jurisdictions. These include the following: early identification of multiple benefits and potential solutions (Man, 2013), which can be particularly important in areas of shared land use (Department of Environment, Food and Rural Affairs, 2011); improved understanding of interdependencies amongst multiple infrastructure owners; and increased innovation and efficiency across the supply chain (Dubois et al., 2011).

Tools have been developed to help planners consider risks associated with interdependencies. An example developed in Australia enables a systems-wide analysis of climate risks to organizations, as well as upstream and downstream interdependencies (Cross Dependency Initiative, 2019). Outcomes can demonstrate which 'third-party risks" can affect an organization's system, as well as the consequences of their own failure risks to other critical infrastructure, and can facilitate collaborative adaptation measures (Cross Dependency Initiative, 2019).

Case Story 7.8 provides an example of how stakeholders have come together to collectively explore interdependencies with transportation, as well as climate change risks to infrastructure and operations, in Surrey, BC.

Case Story 7.8: Addressing increasing flood risk in Surrey, BC

Flood controls in Surrey, British Columbia, were initially developed in the late 1800s. Projected sea-level rise increases the risks of a major flood event, affecting not only residents of Surrey but also the regional and national economy (City of Surrey, 2018). The flood hazards include inundation of a network of regional infrastructure (including water and sewer lines, roadways and highways servicing 200,000 daily vehicle trips across the floodplain), and green infrastructure delivering critical ecosystem services (such as salt marshes and wetlands). The nationally significant economic activities exposed to coastal flood risk include:

- Transportation corridors servicing nearly 10 million annual passenger crossings between Canada and the USA (Bureau of Transportation Statistics, 2018);
- $3 billion in annual goods movement along the Roberts Bank Railway Corridor and the BNSF Railway (connecting Port of Vancouver Facilities with Canada and the USA, respectively); and
- the primary BC Hydro connection to the Bonneville Power Authority in Washington State.

To manage increasing climate risks, the City of Surrey adopted a bottom-up approach involving multiple asset owners across infrastructure sectors to collaboratively assess the shared risk of coastal flooding (Associated Engineering Limited, 2018). Conversations between asset owners, operators and emergency responders servicing the area flourished as a result of a study tour that allowed participants to see and hear about key infrastructure interdependencies. The infrastructure is complex, and the various organizations face different operational challenges and balance them with long-term capital upgrades in different ways, based on their risk tolerance and available resources.

A shared understanding of climate risk was developed by applying Engineers Canada's Public Infrastructure Engineering Vulnerability Committee Protocol (PIEVC, n.d.). This included a triple-bottom-line assessment to identify the social, environmental and economic drivers that are common amongst the owners. Given the distributed benefit of conducting the assessment, funding through the Municipalities for Climate Innovation Program was critical to foster early collaboration that might otherwise have been limited if cost sharing negotiations were required. Although influences on decision making varied across organizations, positive public perception was a key concern for many asset owners (Associated Engineering Limited, 2018).

The next step will be to develop a long-term framework for asset owners to follow to manage the increasing risk of coastal flooding due to sea-level rise, and to better coordinate investments through infrastructure renewal opportunities and develop win-win-win solutions (Associated Engineering Limited, 2018). Key aspects of the framework will be to formalize appropriate pathways for resolving the geographic and physical interdependencies of each infrastructure owner, and monitoring progress in managing climate risk over time.

In some cases, only a single asset owner is involved. For example, in the City of Surrey, the Engineering and Parks, Recreation and Culture departments are working together to adapt to rising water levels, which are impacting a critical transportation route and parkland. Interdependencies provide an opportunity to access the federal Disaster Mitigation and Adaptation Fund, whereas addressing individual assets in isolation does not meet the federal funding requirements. A cross-departmental adaptation approach has been developed that integrates a flood control structure with a bridge replacement and a riverfront park. Coordinating these actions will reduce overall capital costs, increase cost sharing, accelerate adaptation and increase public support by providing immediate community benefits, in addition to reducing long-term risks.

Asset management and renewal also provide an opportunity to proactively reduce risk exposure. Surrey is using standard renewal cycles to adapt key infrastructure to address projected climate impacts over their design life. For example, infrastructure in Mud Bay (*see* Figure 7.15) is serviced by a drainage pump station that is nearing the end of its functional life, and the replacement station has been designed to be resilient to multiple hazards, including higher water levels, seismic events and ground subsidence. In addition, the flood control dyke will be significantly raised. To adapt to sea-level rise, geographic and physical interdependencies need to be addressed, including the following (*see* Figure 7.15):

1. A provincial overpass that needs to be raised to maintain the approach grade of the railway and to preserve the railway clearance envelope; and
2. The class 1, federally regulated American railway that requires raising to accommodate a higher dyke crest designed to protect infrastructure and avoid a weak point.

The end result is that adaptations to the transportation system were not simply defined by direct physical risks to roads and the railway, but were achieved through a coordinated approach to enhance resilience across multiple sectors. This approach enabled actions that meet the needs of each sector as established through a participatory and collaborative process.

Figure 7.15: Interconnected infrastructure in Mud Bay, Surrey, BC highlighting the need for coordinated approaches in addressing risks presented by sea-level rise and other hazards. Source: Adapted from the City of Surrey, 2018.

7.7.5 Moving forward

Changing climate and extreme weather continue to pose challenges to Canada's transportation sector. A range of interdependencies exists within the sector (between transportation modes) and across sectors. Without consideration of interdependencies and interrelated risks, individual investments to improve climate resilience will be limited in effectiveness or will result in unexpected or unintended consequences. Collaborative approaches can help asset owners and operators better understand the range of potential risks and identify adaptation solutions that respond to and cut across multiple risk areas. There are practical examples, including the City of Surrey (*see* Case Story 7.8), that demonstrate the multiple benefits that can be produced through such partnerships, trust and more informed planning.

7.8 Climate change is leading to transformational changes in tourism

All tourism destinations need to adapt to climate change impacts on tourism assets and altered competitiveness within the highly interconnected tourism economy. While Canadian tourism competitiveness is expected to increase under climate change, the specific market and regional implications of this change for national competitiveness remain under-researched. Winter and northern tourism and recreation are particularly sensitive to climate variability, and transformational changes in ski, snowmobile and Arctic cruise tourism are expected.

Tourism is Canada's largest service sector. Climate change is influencing Canadian tourism operations, investment and travel patterns, requiring adaptation by all tourism destinations. Many risks and some opportunities will progressively increase over this century, causing geographical shifts to enable seasonal and nature-based tourism markets to thrive. Earliest impacts have been visible in winter tourism markets, where declining snow and ice conditions are affecting the viability of multi-billion dollar tourism industries across Canada, much of which is concentrated in small and rural communities. The ski industry has invested hundreds of millions of dollars in snowmaking, providing substantial capacity to adapt to future warming and reduced natural snow fall in some locations. Higher warming scenarios will exceed the technical limits of snowmaking adaptation in many locations. The snowmobile industry is highly vulnerable to the same changes because snowmaking is not technically or economically viable for thousands of kilometres of trails, and ice crossings will become increasingly unsafe. Melting glaciers and reduced sea ice are altering tourist attractions from the Rocky Mountain national parks to polar bear and Arctic cruise tourism in the Canadian Arctic Archipelago. Tourists, tourism operators and destination communities are adapting to these diverse climate risks and opportunities, sometimes with unintended consequences for non-tourism government agencies (e.g., search and rescue), communities (e.g., overtourism) and visitor experience.

7.8.1 Introduction

Climate change poses diverse risks and opportunities to domestic and international tourism across Canada (Scott et al., 2020; Hewer and Gough, 2018; Scott et al., 2012). Climate change is already influencing tourism operations, investment, and travel patterns so that all tourism destinations will need to adapt to impacts on local tourism assets, as well as to altered competitiveness within the highly interconnected international tourism economy (Scott et al., 2020, 2016). Globally, high emission pathways are widely considered to be incompatible with projected tourism growth (Scott et al., 2019; IPCC, 2018). Based on the various analyses of the multiple impacts of climate change on the tourism sector, Canada's international tourism competitiveness is expected to improve (Scott et al., 2019; Roson and Sartori, 2016; OECD, 2015). The impacts of changing seasonality, landscapes (e.g., beaches, water levels), biodiversity, extreme events (e.g., heat waves, forest fires) and transnational markets have far-reaching, yet under-researched, implications for tourism development and competitiveness, travel patterns and livelihoods.

An overview of broad climate impacts and adaptation actions in the Canadian tourism industry was provided in Kovacs and Thistlethwaite (2014), including a discussion of implications for the parks system, warm- and cold-weather recreation, and nature-based tourism. While noting examples of advanced adaptation planning efforts, the overview concluded that the level of preparedness across the tourism sector to deal with climate change was low, which is consistent with assessments of the sector's preparedness globally (Becken et al., 2020; Scott et al., 2016). Climate change also presents emerging opportunities for some tourism markets, who would also need to adapt in order to realize potential economic benefits, sustain tourism assets and maintain visitor experience.

This section builds on the findings of Kovacs and Thistlethwaite (2014) by focusing on snow- and ice-dependent markets like ski, snowmobile and Arctic cruise tourism, because these are where the impacts of changing climate are being experienced first and where adaptation by the tourism industry and investors is ongoing. Details of observed and projected changes in snow and ice cover (including sea, lake and river ice, glaciers and permafrost) are presented in Chapter 5 of *Canada's Changing Climate Report* (Derksen et al., 2019).

7.8.2 Winter sports tourism

The ski industry of North America has invested hundreds of millions of dollars in snowmaking over the last 30 years to reduce its climate sensitivity. While average winter temperatures have continued to rise, the length of ski seasons increased throughout the 1980s, 1990s and 2000s in all five regional ski markets in the United States (Scott and Steiger, 2013). Only in the 2010s has this trend reversed, suggesting that advanced snowmaking capacity may no longer be able to offset winter warming. Recent record warm winters that are analogues for normal future winter conditions provide important insight into how the ski industry and ski tourists adapt. During the record warm winter of 2011–2012, the Ontario ski market experienced an average decrease in the ski season length (-17%) and in skiable terrain (-9%), reduced snow quality (-46% days with packed powder), fewer snowmaking days (-18%) and increased early season snowmaking (+300% in December), as well as a 10% decrease in overall skier visits, when compared to a climatically normal winter for the 1981–2010 period (Rutty et al., 2017). Similar impacts on season length and visitation have been observed in the Quebec market, with skier visits reduced by 12.5% in the record warm winter of 2015–2016 (Association des Stations de Ski du Québec, 2016).

Differences in exposure to climate change risk among ski destinations have important implications for intra- and inter-regional market competitiveness and geographical shifts in ski tourism. A comparison of climate change impacts on the ski seasons in ski areas in Ontario, Quebec and the Northeastern United States revealed different futures for these regional markets for the 2050s and 2080s (*see* Figure 7.16). Ski areas in Quebec and high-elevation locations in Vermont and New Hampshire are more climate-resilient than those in Ontario and lower-elevation/lower-latitude locations in the US Northeast (Scott et al., 2020). Analysis of three ski areas in Quebec projected almost identical season losses of 10 to 20 days in the 2050s, and an expected 10% reduction in skier visits (Da Silva et al., 2019). Important information gaps remain, such as for Canada's largest ski tourism markets (British Columbia and Alberta) and regarding the implications of differential impacts on market dynamics, tourism and community-level employment, development pressures and vacation real estate values (Scott et al., 2017; Rutty et al., 2015).

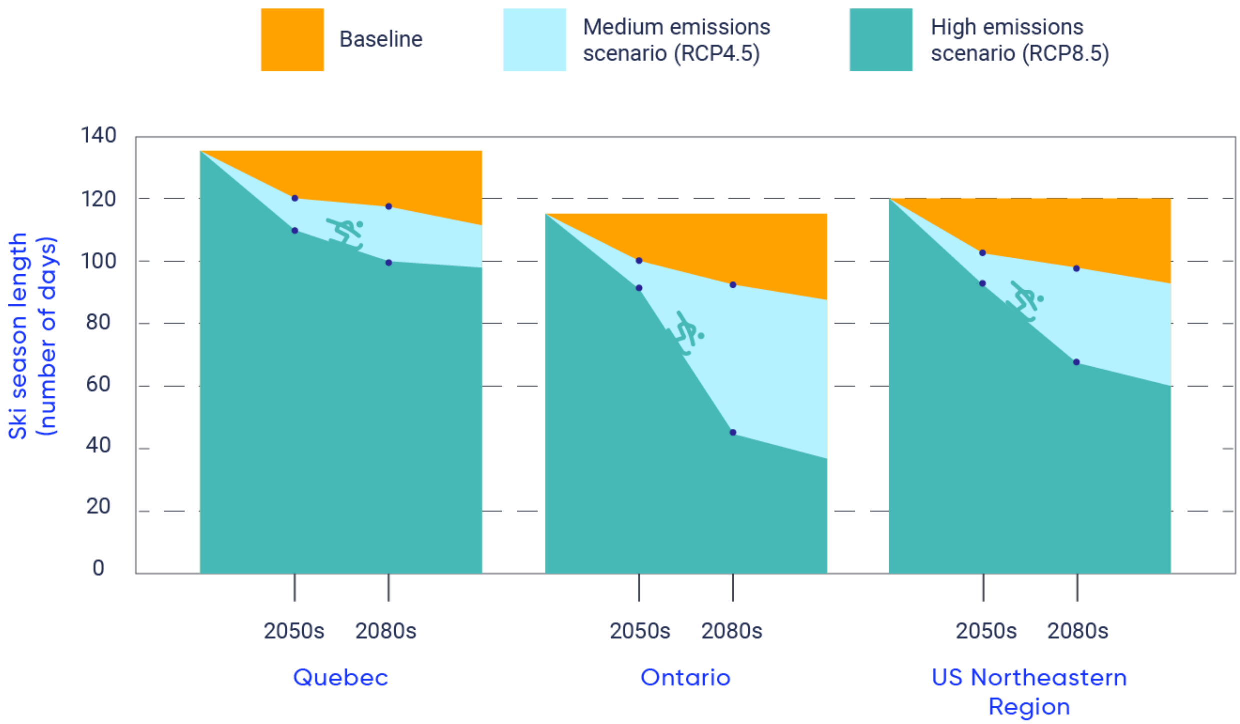


Figure 7.16: Inter-comparison of changes to ski season length in Ontario, Quebec and New England markets with advanced snowmaking capacity under medium emissions (RCP4.5) and high emissions (RCP8.5) scenarios for the 2050s and 2080s. Baseline refers to the period 1981–2010. Source: Adapted from Scott et al., 2020.

Studies of the impact of ongoing and projected reductions in winter season snow on the snowmobile industry of North America show that while riders are adapting to changing conditions, continued deterioration of the season length will result in loss of this tourism market in many regions of the US and Canada (Perry et al., 2018; Hatchett and Eisen, 2018; Tercek and Rodman, 2016; McBoyle et al., 2007). Under the high-emissions scenario projected for the 2050s, a reliable snowmobiling season will be largely eliminated in regions of Ontario and Quebec with the densest network of snowmobile trails (McBoyle et al., 2007). A 20% decline in registered snowmobiles in Canada from 1995 to 2015 (International Snowmobile Manufacturers Association data) may signify a climate adaptation by individuals that will induce changes in this tourism marketplace. Bombardier Recreational Products (2017) advised investors that global climate change might impact future snowmobile sales to a greater extent than previously anticipated. A shift to all-terrain vehicles is not thought to be a feasible adaptation strategy, as these vehicles tend to be more impactful on trail surfaces, preventing shared trail networks and access by other users to parks and farmlands (Perry et al., 2018; McBoyle et al., 2007).

7.8.3. Arctic cruise tourism

Declining summer sea ice cover has allowed greater marine access to the majestic land, seascapes and cultures of the Canadian Arctic (*see* Northern Canada chapter). This has opened up access to areas and communities that were previously inaccessible to tourist vessels. Tourism operators and tourists have been quick to adapt to these new opportunities, with strong growth in commercial (cruise ships) and non-commercial (private yachts) tourism vessel traffic since the late 2000s (Dawson et al., 2018; Johnston et al., 2017). Although tourism development is considered highly strategic by pan-Arctic governments (Dawson et al., 2017), there are concerns related to infrastructure needed for hosting the growing tourist numbers, environmental impacts, uneven economic opportunities, negative local social and cultural impacts, and limited search and rescue capacity (Dawson et al., 2018; Stewart et al., 2011). Limited hydrographic charts and changing ice conditions increase the risk of a high-impact cruise ship incident (Dawson et al., 2016). Even relatively minor incidents can be associated with high costs (*see* Case Story 7.9). Integrated multi-sector adaptation is essential to respond to these challenges and support sustainable tourism in the Canadian Arctic.

Case Story 7.9: The costs of increased tourism ship traffic in the Canadian Arctic

Unregulated cruise ship and pleasure craft (yacht) tourism traffic has been growing steadily in the Canadian Arctic as a result of changing ice conditions (*see* Figure 7.17; Dawson et al., 2018). This response by tourism operators and tourists has raised concerns over the potential for search and rescue capacity to respond to a high-risk incident, such as the sinking of a cruise ship. The grounding of the Akademik Ioffe near Kugaaruk, Nunavut in August 2018 revealed the high costs of search and rescue for even a minor incident involving a tourism vessel. The Canadian Forces spent over $500,000 to provide assistance, while the cost of two icebreakers that also responded were not reported by the Canadian Coast Guard (Toth, 2018). Investment in improved navigation charts in common shipping routes and insurance requirements to indemnify search and rescue costs have been identified as possible adaptation responses to reduce safety and financial risks.

Figure 7.17: Cruise ship Hanseatic arriving in Pond Inlet, NU, ca. 2005. Photo courtesy of Emma J. Stewart, Lincoln University.

7.8.4 "Last chance" tourism

Some evidence supports the emergence of a travel trend of "last chance" tourism. This refers to travel by tourists to visit sites before their attractions vanish or are irrevocably degraded, or to witness the impact of climate-induced landscape changes, such as rapidly melting glaciers or biodiversity changes (Lemelin et al., 2010). Tourist market surveys about Canada's Rocky Mountain Parks and Churchill, Manitoba, the self-declared polar bear capital of the world, reveal last-chance motivations among a segment of travellers, suggesting short- to medium-term opportunities for increased visitation, as well as visitor education and interpretive activities (Weber et al., 2019; Lemieux et al., 2017; Groulx et al., 2017; Groulx et al., 2016; Dawson et al., 2010). There remain important uncertainties associated with longer-term tourist responses to degraded tourism assets. For example, while tourists have indicated their motivation and intent to visit the Rocky

Mountain Parks or Churchill, the number of tourists would decline if glaciers and polar bear populations were significantly impacted, and it is uncertain whether future generations of tourists with no experience or expectations of current ecotourism attractions would respond in the same way (Scott et al., 2007).

7.8.5 Moving forward

Tourism is Canada's largest service sector and is projected to become more competitive in the global market as a result of climate change (Scott et al., 2019; Roson and Sartori, 2016; OECD, 2015). The current literature is insufficient to determine the net economic impact of low- and high-emissions scenarios on sub-national tourism markets. Most adaptation in the sector is focused on addressing ongoing operational risks and emerging market opportunities. A key barrier to longer-term strategic adaptation planning remains the lack of integrated sectoral assessments that consider the full range of potentially compounding impacts at national and destination scales, and their interactions with other major drivers of tourism. Tourism is not part of any major national climate policy documents in Canada, nor is there a climate change response in national and most sub-national tourism strategies (Becken et al., 2020). Adaptation that is occurring is often at the company scale, with limited examples of coordinated adaptation planning at destination scale (e.g., Resort Municipality of Whistler, 2016).

7.9 Increased private sector involvement will accelerate adaptation across sectors

Despite growing awareness of climate change impacts, there is no widespread evidence of corporate adaptation in Canada. When adaptation does occur, it tends to focus on short-term actions to address physical risks, such as disruptions in construction and interruptions in supply chains. Increased involvement of the private sector would accelerate adaptation in Canada as a whole.

There is considerable uncertainty about the role of the private sector in climate change adaptation in Canada. While there are several case studies of Canadian businesses adapting to changing climate, particularly in the insurance and natural resources sectors, there is no evidence that such actions are broadly representative of the business community response to climate change. Actions that have been taken are frequently "low-hanging fruit" focused on site-specific vulnerabilities to the current climate that would have been implemented regardless of increasing risk in the future. Drivers for corporate adaptation include strategic incentives associated with physical risk, growing awareness among stakeholders of the need to adapt, and government regulation. The lack of available data on corporate adaptation may be influenced by the proprietary protection of internal information; however, there are also clear barriers to adaptation related to capacity and the short-term time horizons of most business operations. Additional effort, including research, could help reduce these barriers by identifying the appropriate roles for the private sector in supporting adaptation.

7.9.1 Introduction

The private sector, which is a key component of all the sectors discussed previously in this chapter, is both a source of risk and opportunity in Canada's approach to climate change adaptation. Research highlights the exposure of firms and industries to climate change, particularly how changing environmental conditions (e.g., more frequent extreme weather) could limit growth, disrupt operations and devalue investments. At the same time, firms and industries are critical actors in supporting the development of expertise, tools and knowledge related to adaptation.

Private sector engagement on climate change has historically focused on GHG emissions reduction rather than adaptation. However, governments, scholars and other organizations have started to explore the potential role of corporate adaptation, given the scale of the investment and resources required to manage climate change risks (Dougherty-Choux et al., 2015). The private sector could help to address demands for new technologies, expertise in risk management and modelling, capacity to scale up solutions beyond individual communities, and financial resources needed to achieve domestic and international adaptation objectives (UNFCCC, 2012; UNEP, 2012).

An overview of climate impacts and adaptation actions in Canadian businesses was included in multiple chapters of Warren and Lemmen (2014), with Kovacs and Thistlethwaite (2014) noting that corporate adaptation had been largely reactive, responding to variations in weather or extreme events, rather than involving analysis of long-term projected changes in climate. They further noted that successful adaptation can create new opportunities through expanded markets and products. They emphasized the scarcity of published research detailing climate impacts and adaptation on Canadian businesses, noting that in some cases adaptation actions may be under-reported for strategic reasons.

This section builds on the findings of Kovacs and Thistlethwaite (2014) by focusing on the status of corporate adaptation in Canada broadly. It complements the discussion of specific adaptation actions in other sections of this chapter, as well as a number of emerging issues of importance to the private sector, which are discussed in the Climate Disclosure, Litigation and Finance chapter of this report.

7.9.2 Corporate adaptation in Canada

Corporate climate change adaptation is defined as a "process of adjustment by companies to actual or expected climate and its effects through changes in business strategies, operations, practices and/or investment decisions" (Averchenkova et al., 2016, p. 520). Cases of corporate adaptation in Canada, as well as internationally, tend to be limited and difficult to generalize beyond sector and site-specific actions. Comprehensive literature reviews on corporate adaptation (Linnenluecke and Smith, 2018; Averchenkova et al., 2016) did not identify any recent (post-2011) Canadian studies on corporate adaptation.

Research findings from other industrialized countries indicate that firms may have extensive experience in making management or operational adjustments in response to changing economic or competitive environments, but they have generally been unable to translate that experience into making adjustments to changing climate (Linnenlueke et al., 2013). As a result, firms often separate climate change adaptation from the main value-driving processes, and instead treat it as a social responsibility issue (Thistlethwaite and Wood, 2018; Furrer et al., 2009).

It is often difficult, and perhaps not particularly useful, to distinguish actions supporting climate change adaptation from actions arising from existing risk management processes, given that anticipating and identifying external instability that could interrupt services is effective business continuity planning (Agrawala et al., 2011). Experts have argued that adaptation can be incorporated into standard enterprise risk management strategies by expanding the scope of risk assessment, prioritization and response actions to include climate change (Berkhout, 2012).

7.9.3 Adaptation actions

Risk management represents the main strategy for firms to reduce their exposure to climate change. In analyzing private sector adaptation, it is possible to differentiate between firm-level management actions to limit operational exposure to climate change, and the production of adaptation tools and services that help manage climate vulnerability (Schaer and Kuruppu, 2018). In terms of managing operational exposure, adaptation actions can be categorized as either “soft” or “hard” measures. “Soft” adaptations constitute “low-regret” measures, as they require limited investment and will yield benefits, although not always direct financial returns. They include activities such as climate change risk and opportunity assessment, adjusting operational practices, education and awareness programs, stakeholder and political engagement, and initiating partnerships with external actors. In contrast, “hard” adaptation measures require a significant investment or change in practice and operations, such as building or renovating structural defenses, relocating infrastructure or offices, or divesting from climate-exposed property and sectors (Averchenkova et al., 2016). Adaptation services represent a response to demand for climate change risk and disaster risk management, and include climate risk and opportunity assessments, mapping and communication technologies, climate change-resilient agricultural products, and new insurance products (e.g., parametric insurance).

Adaptation is growing in the corporate sector in response to many drivers, including increasing awareness of climate change among firms and sectors, strategic incentives associated with addressing physical risks, (Williams and Schaefer, 2013) and government regulations (Revell et al., 2009). In Canada, attention has focused primarily on the understanding and disclosure of physical risks. These include disruptions in construction, interruptions in supply chains, volatile energy costs associated with climate-related changes in demand, and closures or relocation in situations where employees or customers are unable to access a firm as a result of extreme weather (*see* Climate Disclosure, Litigation and Finance chapter; Certified Professional Accountants Canada, 2016a; Linnenluecke et al., 2011). Despite this emphasis, most firms struggle to measure physical risk that involves a lot of uncertainty and can be perceived as a more long-term concern (*see* Climate Disclosure, Litigation and Finance chapter; Mazzacurati, 2018).

Overall, there is limited evidence of clear responses to these drivers in Canada. A 2018 survey focused on business responses to climate change found that a majority of businesses are not taking action and one quarter of respondents suggest that they plan to engage in adaptation (Earnscliffe Strategy Group, 2018). One example is the insurance industry implementing strategies to support climate change adaptation in response to significant increases in water-related property damage (*see* Case Story 7.10; McBean, 2012). Climate change, combined with ageing infrastructure and development in areas where climate risks are high, have increased the number and costs of claims for flood damage (Henstra and Thistlethwaite, 2017).

Case Story 7.10: Insurance and climate change adaptation in Canada

The 2013 flood in southern Alberta was the costliest flood in Canada's history. Unfortunately, damage from overland flow of water from the flood did not qualify for property insurance, leaving many victims without resources for a full recovery. This gap in coverage led insurers to question whether Canadians had sufficient coverage for a changing climate where flood risk is anticipated to increase (Certified Professional Accountants Canada, 2016b). In response, insurers expanded their coverage to include overland flood damage, which had previously been unavailable in Canada. The availability of flood insurance provides an important tool for enhancing climate resilience by assigning premiums that create an incentive for property owners, businesses and communities to reduce their own exposure through expansion of coverage, and also by sharing the recovery costs from flood impacts when they occur (Thistlethwaite, 2016; IPCC, 2012). This engagement has enabled broader utilization of insurance expertise on risk modelling and strategies for risk reduction in efforts to promote adaptation (Surminski and Hankinson, 2018). This is particularly important in Canada where flood risk awareness and an understanding of insurance coverage are limited throughout the country (Thistlethwaite et al., 2017).

7.9.4 Knowledge gaps

Apart from a few examples in the insurance industry and natural resource sectors, there is a paucity of available research and data on corporate adaptation in Canada. Knowledge gaps start with the fact that corporate adaptation remains poorly defined in practice, which limits our understanding of which management, strategic or investment behaviours constitute adaptations. As a consequence, firms might be under-reporting adaptation since they are unsure if an action can be defined as such.

There also remains uncertainty over the motivation for and barriers to corporate adaptation. In Canada, most attention has focused on physical risks to business operations, but there is almost no research on the topics of firm awareness or regulation. There is also little research on the outcomes of corporate adaptation and its impacts on firms or the communities where they are located. Monitoring and evaluation of corporate adaptation could improve understanding of these outcomes (Surminski and Hankinson, 2018; Averchenkova et al., 2016). Finally, additional research would help to clarify the role of businesses in broader adaptation policies. The division of responsibility for adaptation between different stakeholders remains a source of ambiguity.

These knowledge gaps are particularly concerning for small and medium-sized enterprises (SMEs), which are more vulnerable to climate risk (Linnenluecke and Smith, 2018). SMEs lack the resources of their larger counterparts and may have greater difficulty prioritizing perceived long-term issues like climate change, given short-term concerns around sustaining operations. The 2018 survey of Canadian business responses to climate change found that SMEs were far less likely to be engaging in actions supporting adaptation (Earnscliffe Strategy Group, 2018). This gap is especially concerning since the recovery of a local community in the aftermath of a disaster is often contingent on the resiliency of local SMEs. There is evidence that 40% of SMEs fail to reopen after a disaster and that many are unable to sustain their business even if they do reopen (McKay, 2018). Without these SMEs, the local community may never support the economic growth and quality of life enjoyed before the disaster, since many provide critical services such as access to food and medicine.

7.9.5 Moving forward

While the lack of available data precludes strong conclusions about the status of corporate adaptation in Canada, it suggests that firms may lack sufficient adaptive capacity. Most firms face limitations in the human and financial resources required to interpret climate change data, assess the costs and benefits of actions, and incorporate the flexibility required to adjust strategies as new information emerges (Wedawatta and Ingirige, 2016; Downing, 2012). Research also suggests that firms are organizationally biased in favour of short-term and local scales, and resistant to acting when faced with temporal and spatial uncertainty associated with climate change (Bansal et al., 2017; Slawinski et al., 2017). The lack of adaptive capacity and absence of organizational interest in addressing climate change call into question the current ability of businesses to have a role in supporting climate change adaptation.

7.10 Moving forward

7.10.1 Knowledge gaps and emerging issues

It has been noted for more than a decade that, in most situations, existing knowledge is sufficient to start taking adaptation action in Canada (Lemmen et al., 2008). Nonetheless, the need to accelerate the implementation of adaptation measures has been acknowledged in both scientific and policy analyses at the global and national scale (e.g., Canadian Council of the Academies, 2019; IPCC, 2018; Government of Canada, 2016; UNFCCC, 2015). Risk and opportunity assessments are frequently a prerequisite to enhancing investment in adaptation. A wide range of methodologies are available, with the most appropriate being determined by many factors, including the scope and goal of the assessment and available resources (e.g., British Columbia Ministry of Environment and Climate Change Strategy, 2019). The Canadian Council of Academies undertook an assessment to prioritize climate change risks for Canada and the Canadian federal government, based largely upon collective expert judgement (Canadian Council of Academies, 2019). Major climate change risk areas included some of the sectors discussed in this chapter as stand-alone sections (agriculture, fisheries, forestry) as well as themes woven throughout (e.g., physical infrastructure and governance and capacity). Importantly, analysis considered the potential to reduce damages through adaptation, in addition to the likelihood and potential consequences associated with each risk. Of the topics addressed in this chapter, infrastructure (including transportation) and agriculture were identified as having the highest adaptation potential, and fisheries the lowest (Canadian Council of Academies, 2019).

While many factors contribute to the lack of progress on adaptation, uncertainties and gaps in knowledge are frequently highlighted as a barrier to action (Eyzaguirre and Warren, 2014). Knowledge gaps specific to individual sectors are identified in the preceding sections of this chapter and the publications cited in those sections. There are also a number of emerging cross-cutting issues that represent important knowledge gaps with respect to economic sectors in Canada.

The state of adaptation in the private sector

While climate disclosure is emerging as a key instrument for understanding how the private sector is assessing and responding to physical climate risk (*see* Climate Disclosure, Litigation and Finance chapter; TCFD, 2017), such information is largely restricted to large, publicly-traded companies. Very little information is available on adaptation actions undertaken by small and medium-sized businesses, even though many are highly exposed to climate risks. Benchmark surveys (e.g., Earnscliffe Strategy Group, 2018) provide a foundation for future work.

Transnational climate impacts

Also referred to as transboundary or indirect impacts, these refer to climate impacts that occur in one country and affect the adaptation measures taken within other countries (Hedlund et al., 2018). These could relate to impacts on global supply chains, international competitiveness, financial flows and trade (*see* International Dimensions chapter). For example, flooding in Thailand in 2011 affected global electronics and automotive supply chains, with economic implications for many countries and corporations (Shughrue and Seto, 2018). The magnitude of such vulnerabilities in Canada is essentially unknown, although research elsewhere indicates that open and export-intensive economies are particularly exposed (Hedlund et al., 2018).

Interdependencies

Much of the existing sectoral research examining climate impacts in Canada, and elsewhere, has been focused on individual sectors. While the importance of understanding interdependencies between sectors is growing (*see* Section 7.7.3), quantitative analysis of these connections remains limited. Without such analysis, there is potential to significantly underestimate the risks associated with climate change (Canadian Council of Academies, 2019).

Potential for stranded assets

Understanding of the risk of assets losing significant value as a result of policy changes to address climate change is well developed, particularly with respect to the energy sector (e.g., IPCC, 2018; IRENA, 2018). Far less attention, particularly in Canada, has been given to stranded assets that could result from the physical impacts of climate change (*see* Circle of Blue, 2018 for examples related to water resources). In Canada, closure of the rail link to the Port of Churchill for 18 months as a result of flooding represents temporary stranding of the port assets (*see* Section 7.7.3).

Strengthened economic analysis

A commonly cited barrier to adaptation action is the absence of a strong business case (Eyzaguirre and Warren, 2014). While examples of detailed economic analysis, including cost-benefit, cost-effectiveness and multi-criteria analyses, exist (e.g., UNFCCC, 2011) there is limited application of these techniques in Canada (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter). At a national scale, quantitative analysis of economic impacts under a range of future climate scenarios is lacking, potentially hindering action to enhance climate resilience and reduce greenhouse gas emissions.

7.11 Conclusion

Examination of the sector-specific key messages and associated discussions in this chapter reveals several integrative conclusions:

1. A tremendous breadth of sector activities are impacted by climate change, which is evident despite authors focusing on a limited number of key issues per sector. While research has traditionally focused on direct climate impacts on production (e.g., agriculture, forestry, fisheries and hydroelectricity) and to a lesser degree on consumer demand (e.g., energy and tourism), it is clear that cumulative and cascading impacts of climate change ultimately affect virtually all elements of sectoral systems. This breadth emphasizes the value of comprehensive assessments of both risks and opportunities to inform adaptation.
2. It is important to understand the interconnections within and between multiple sectors (*see* Section 7.7.3). For some sectors, such as transportation, this is particularly evident given its critical role in supply chains (*see* Section 7.7.3). The reliability and resilience of Canada's freight transportation system regarding access to domestic and international markets is a critical issue for the sustainability of agriculture in Canada (*see* Section 7.4.3). The response of the forest sector to wildfire has implications for many other sectors, including costs related to evacuations, damage to buildings, roads, pipelines and other physical infrastructure, shutdown of businesses and industries, and insurance costs (*see* Section 7.2.2). Emerging tourism in the Arctic is having unforeseen social and cultural impacts, and is placing stress on search and rescue capacities (*see* Section 7.8.3). Further modelling studies could help elucidate the nature of these interconnections (*see* Section 7.7.4).

3. Adaptation is occurring within all sectors, but needs to be accelerated. This applies to actions that reduce risks and those that take advantage of new opportunities. It is noteworthy that successful adaptation not only reduces the vulnerability of sectors and communities within Canada, but also enhances global resilience (e.g., food security) (*see* Sections 7.3.1, 7.4.3). Most examples of implemented adaptation action relate to those sectors where the direct impacts of climate change are already evident. Evidence of widespread adaptation within the private sector is particularly limited, despite the key role that it plays in all the sectors discussed here (*see* Section 7.9.2). The need for collaboration using a systems approach that includes producers, asset managers, regulators, researchers and relevant stakeholders is a commonly identified need (*see* Sections 7.2.3, 7.4.1, 7.5.5, 7.6.4, 7.7.4). Finally, it is extremely important to monitor and report on adaptation measures that have been implemented in order to inform future plans (*see* Sections 7.5.4, 7.6.4, 7.10).

4. There is urgency associated with accelerating adaptation action. Urgency is most clear where current climate risks are not adequately managed and where investment decisions made today have implications extending for many decades to come: for example, decisions regarding infrastructure (*see* Sections 7.6, 7.7, 7.8), forest management (*see* Section 7.2) and mining reclamation (*see* Section 7.5). While proactive adaptation is generally recognized as being more effective and cost-efficient than reactive approaches (i.e., responding to impacts as they happen), and provides opportunities for innovation and competitive advantage (e.g., Eyzaguirre and Warren, 2014), it is recognized that investment decisions in both the public and private sectors take place within a context of competing priorities and associated opportunity costs. Comprehensive assessments of risks and opportunities can be critical in identifying action priorities, particularly those that include consideration of adaptation potential (*see* Sections 7.7.3, 7.8.5, 7.10). There is also an urgent need to reduce greenhouse gas emissions as the range of viable adaptation options decreases under higher rates of climate change, and limits to adaptation can be exceeded (IPCC, 2018, 2014).

7.12 References

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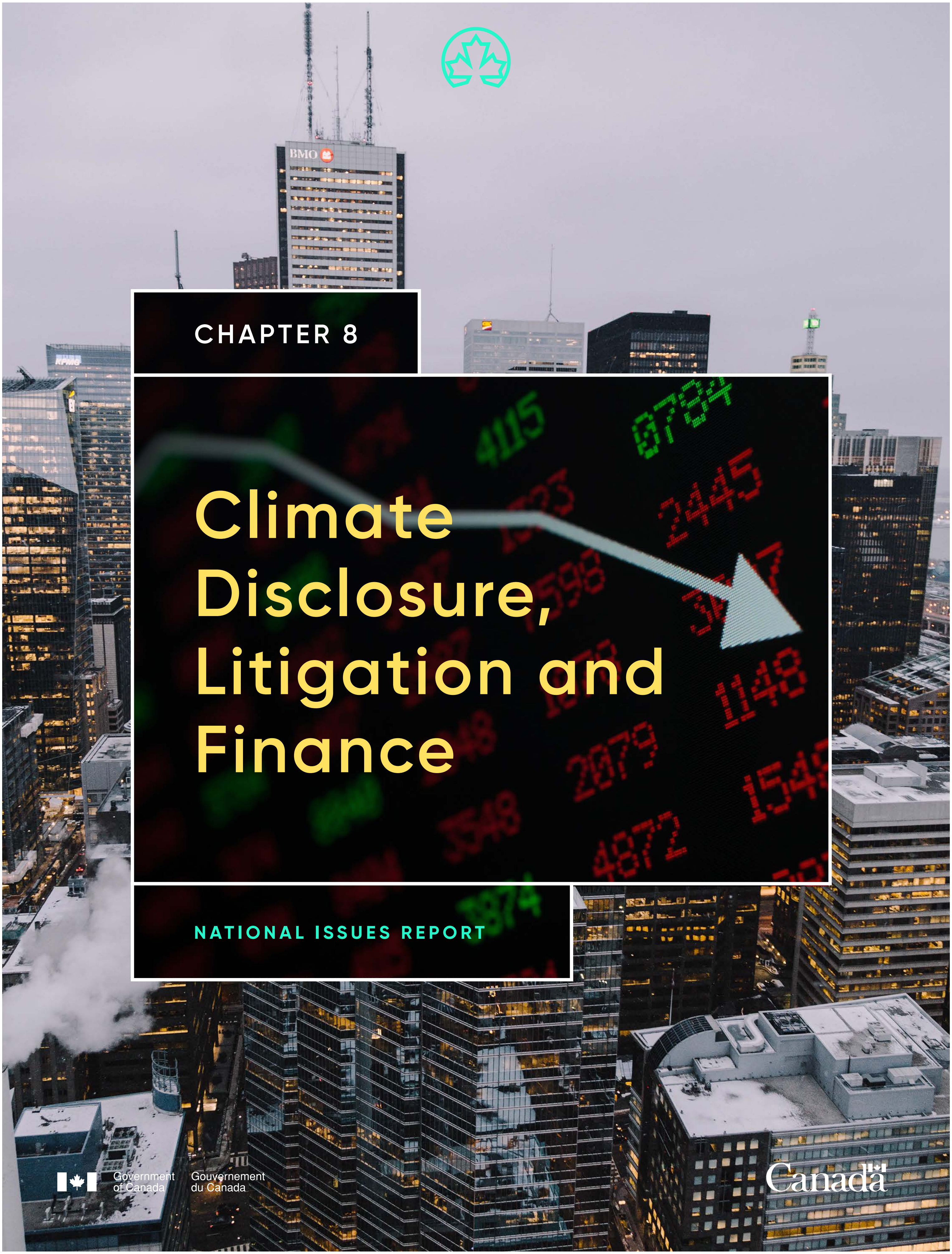

CHAPTER 8

Climate Disclosure, Litigation and Finance

NATIONAL ISSUES REPORT

Government of Canada / Gouvernement du Canada

Canada

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Key messages

Climate change risks and opportunities are business issues (*see* Section 8.2)

Most industries and sectors in Canada are exposed to climate-related risks and opportunities, which are projected to increase over time. These risks and opportunities are increasingly recognized as a business issue, which present incentives for businesses to contribute to the transition to a climate-resilient and low-carbon economy.

Climate-related disclosure drives climate action (*see* Section 8.3)

Increased financial disclosure of climate risks and opportunities will inform and enhance action to reduce climate change impacts. Guidance for climate-related disclosure is evolving and is increasingly being adopted.

Transitioning to a climate-resilient and low-carbon economy requires significant investments (*see* Section 8.4)

There is a large financing gap for transitioning to a climate-resilient and low-carbon economy in Canada. Significant public and private capital are required to address this gap, but obstacles limit the opportunities to attract the appropriate amount of capital.

Investments in climate risk reduction build resilience (*see* Section 8.5)

Investments in disaster resilience have demonstrated their effectiveness for reducing exposure to physical climate risks. Opportunities exist for governments, businesses and individuals to improve their resilience to physical climate risks to break the trend of increasing loss and damage from climate events.

Climate litigation is increasing against governments in Canada (*see* Section 8.6)

Climate change litigation is increasing against governments and their agencies in Canada. There is growing litigation seeking to compel or change governmental action, approvals or decisions, as well as lawsuits seeking financial compensation related to failure to adapt infrastructure.

Climate litigation against the private sector is a potential risk (*see* Section 8.7)

While there has been virtually no climate litigation in Canada against private sector companies, Canadian companies are increasingly assessing potential climate litigation risks.

8.1 Introduction

Climate change is now widely regarded as an environmental and economic issue. Most industries and governments are exposed to climate-related risks. This chapter examines the evolving issues of climate disclosure, litigation and finance for businesses and governments. Due to the nature of these topics, the volume of peer-reviewed literature is limited, particularly as it relates to Canada. Therefore, this chapter draws more upon primary information sources and less upon assessment of the academic literature than do other chapters in this report.

8.1.1 International initiatives

In 2015, the United Nations Member States adopted three international framework agreements related to climate change and climate risk: the Paris Agreement (United Nations Framework Convention on Climate Change, 2015), the Sendai Framework for Disaster Risk Reduction (United Nations, 2015) and the 2030 Agenda for Sustainable Development (Sustainable Development Goals, 2015). These agreements emphasize the importance of considering climate change and disaster risk reduction in shaping sustainable and resilient development pathways.

While the policy discussion about climate change emphasizes the need to reduce greenhouse gas (GHG) emissions and adapt to better cope with the impact of extreme events, the business community is increasingly focused on managing physical and transition risks, as set out by the Financial Stability Board's industry-led Task Force on Climate-related Financial Disclosures (TCFD, 2017). These are defined as follows:

- **Physical risks:** Extreme events or long-term shifts in climate patterns that may damage or otherwise impact property, infrastructure, supply chains, transport needs, trade and employee safety; and
- **Transition risks:** Financial and reputational risks that may result from policy, legal, technology and market changes to address GHG emissions reduction and adaptation needs related to climate change.

In addition to these risks, the TCFD identified opportunities for organizations that arise through their efforts to mitigate and adapt to climate change. Opportunities could result from resource efficiency and cost savings, the adoption of low-emission energy sources, the development of new products and services, access to new markets and building resilience along the supply chain. Risks and opportunities vary depending on the region, market and industry in which an organization operates (TCFD, 2017).

The TCFD's final recommendations released in June 2017 (TCFD, 2017) and its subsequent annual status reports confirm that climate change "affects nearly all economic sectors," although to different extents. The TFCD emphasizes the need to integrate climate risk and opportunity into organizational governance and disclosure of climate change-related information to investors. Managing the risks and opportunities associated with climate change could affect a company's ability to access capital, deliver products and services, hire and retain employees, and achieve positive financial performance. For investors, corporate disclosure provides data to facilitate informed investment decisions.

Several countries, including Canada, have begun to realign their financial sector and develop a "sustainable" financing framework that supports climate resilience and the transition to a low-carbon economy, including a "just transition." Some examples include initiatives in the United Kingdom (Green Finance Taskforce, 2018) and Australia (Australian Sustainable Finance Initiative, 2019). These and other initiatives are complemented by global activities in financial and capital markets, the establishment of investor coalitions, changing shareholder sentiments and actions by rating agencies to incorporate climate risk in their sovereign, municipal and company credit ratings (Golnaraghi, 2019a, b; "The Geneva Association, 2018a).

8.1.2 Canadian initiatives

The Pan-Canadian Framework on Clean Growth and Climate Change, released in 2016, sets out a national climate change plan for Canada. The Framework provides a strategy to "grow our economy, while reducing emissions and building resilience to adapt to a changing climate" (Government of Canada, 2016, p. i). In 2019, the Expert Panel on Sustainable Finance issued its recommendations to spur market activities, behaviours and structures to support sustainable finance in Canada. These include, among others, recommendations to develop authoritative sources of climate information in Canada, encourage greater TCFD implementation and embed climate-related risk into the monitoring, regulation and supervision of Canada's financial system (Expert Panel on Sustainable Finance, 2019).

8.2 Climate change risks and opportunities are business issues

Most industries and sectors in Canada are exposed to climate-related risks and opportunities, which are projected to increase over time. These risks and opportunities are increasingly recognized as a business issue, which present incentives for businesses to contribute to the transition to a climate-resilient and low-carbon economy.

More frequent and severe extreme weather events, as well as gradual changes in variables such as sea level and permafrost, present risks of physical damage to private assets and public infrastructure, which translate to material risks with financial implications for businesses. Businesses also need to actively manage the transition to a climate-resilient and low-carbon economy, which includes changes in consumer demand, technology and government policy. In managing these risks and embracing the related opportunities, businesses can help lead the effort to adapt to climate change.

8.2.1 Growing awareness of climate change risks and opportunities

Many businesses are deeply concerned about climate risks (World Economic Forum, 2020), as climate-related risks have become increasingly evident for businesses and governments. Climate action failure is ranked as the number one risk by likelihood and impact in the 2020 Global Risks Report (*see* Figure 8.1). Other climate-related risks, including extreme weather, natural disasters, biodiversity loss and water crises, are also ranked prominently.

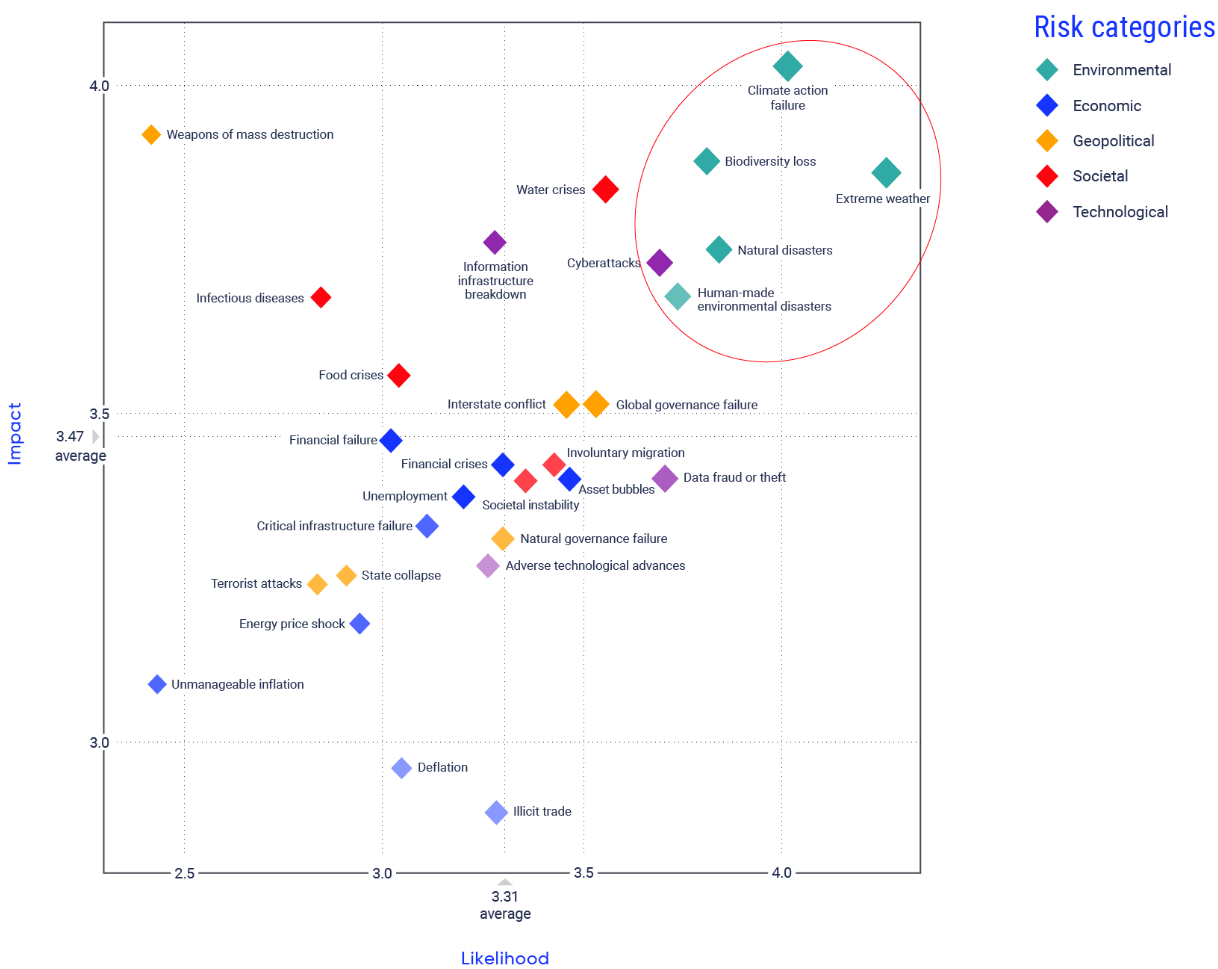


Figure 8.1: Findings from the World Economic Forum Global Risks Perception Survey (2019–2020), where risks were ranked on a scale of 1 to 5 according to perceived likelihood and perceived impact. Environmental risks rank among the highest, both in terms of likelihood and impact. Source: Adapted from World Economic Forum, 2020.

The magnitude of the risks associated with climate change is also reflected in other assessment reports. Canada's Changing Climate Report concludes that "the effects of widespread warming are evident in many parts of Canada and are projected to intensify in the future" (Bush and Lemmen, 2019). The Council of Canadian Academies (CCA) notes that, in addition to warming temperatures, there have been "more frequent heatwaves, changing precipitation patterns, reduced snow and ice cover, thawing permafrost, shrinking and thinning Arctic sea ice and changes in streamflow, all of which are leading to widespread impacts on natural and human systems. The effects of warming are projected to intensify over time" (CCA, 2019, p. ix). Considering these changes, the CCA report identified 12 major areas of climate change risk facing Canada that could involve significant losses, damages or disruptions over the next 20 years. The most acute risks were for physical infrastructure, coastal communities, northern communities, human health and wellness, ecosystems and fisheries.

Businesses in Canada and around the world are working to understand how climate change will affect the risk and opportunity landscape for them and their stakeholders (World Economic Forum, 2020; TCFD, 2017). Extreme weather events and slower-onset climatic trends present risks for all companies and their supply chains, particularly for physical assets and for companies that rely on public or private infrastructure for the delivery of raw materials, inputs or finished goods. A changing climate may also present risks to the health and safety of employees. Additionally, there may be indirect impacts to businesses, including changes in global trade routes, changes in agricultural productivity or in the availability of water and other natural resources. The financial impacts of direct and indirect physical impacts on a Canadian business may include reduced revenues (e.g., losses arising from business interruptions, reduced asset productivity or reduced consumer demand), increased operating costs (e.g., for repairs, increased energy costs for heat waves and negative impacts on workforces), increased capital expenditures (e.g., the cost of repairs to damaged infrastructure, or temporarily or permanently moving to and equipping new sites), early retirement of assets, and the higher cost of and more limited access to capital and insurance.

The insurance industry, for example, has adapted its practices in response to the rising value of severe weather damage claims paid, including by making investments in catastrophe risk models for assessing and pricing risk, and in a variety of other technologies to enhance its capacity to expedite assessment and claim payouts after a disaster. The industry has launched centres of excellence on climate change adaptation and is working closely with Canadian universities on adaptation research and actionable guidance for individuals, households, businesses and government. Examples include the Institute for Catastrophic Loss Reduction (ICLR) at Western University and the University of Waterloo-based Intact Centre on Climate Adaptation (ICCA) and Partners for Action. The industry is also working with governments and businesses in sharing risk information, promoting adaptation by businesses, homeowners and governments by putting a price on the risk of physical damage, and in providing financial incentives for investments in resilience. For example, in partnership with the Government of Canada and provincial governments, through the National Working Group on Financial Risk of Flooding, the industry is sharing flood risk maps, providing guidelines for reducing flood risks, developing solutions for managing financial risk of flooding and introducing residential flood coverage in some regions, with incentives when residents invest in flooding retrofits (Insurance Bureau of Canada [IBC], 2019b). However, there are limits to the insurance industry's ability to respond to climate risks. With unmitigated climate change, climate-related physical risks may become uninsurable (Buberl, 2017).

In addition to physical risks, businesses also face transition risks and opportunities as new technologies are developed, and as markets and the policy environment respond to climate change and the transition to a low-carbon future. Significant investments may be required by businesses to complete the transition. These might include renewable sources of energy, low-carbon transportation, energy-efficient buildings, resilient new construction and resilience retrofits. As new markets open up, old business models may become less viable. These new markets are key considerations for businesses that are determining their strategy and assessing the viability of their business model. Companies must consider whether their business models are resilient as the world transitions to a lower-carbon economy. Many investors are already advocating for companies to change their business models and adopt climate resilience strategies. Climate Action 100+, which includes Canadian asset managers, is one organization that is currently engaging with over 160 corporations globally to this end (Climate Action 100+, 2019).

8.3 Climate-related disclosure drives climate action

Increased financial disclosure of climate risks and opportunities will inform and enhance action to reduce climate change impacts. Guidance for climate-related disclosure is evolving and is increasingly being adopted.

Climate-related disclosure allows investors to make informed decisions on investing towards a climate-resilient and low-carbon economy. Through climate-related disclosure, companies and public-sector entities like cities, municipalities and Crown corporations are encouraged to analyze, better understand and adopt strategies to adapt to climate risks. While Canadian securities laws require publicly-traded companies to disclose material climate risks, investors and other stakeholders often demand additional climate-related information. To meet this demand, many Canadian companies provide voluntary climate-related disclosure in publicly filed sustainability or climate reports. Historically, many climate-related disclosures failed to meet the needs of investors, as they did not report financial impacts and were often not comparable across companies. Frameworks with the goal of improving climate-related disclosures by publicly-traded companies and public-sector entities now exist and are being further developed. As investor and other stakeholder expectations continue to evolve, these companies and entities may need to enhance their climate-related disclosure to meet these expectations.

8.3.1 Importance of climate-related disclosure

Disclosure is the process used by organizations to provide information that enables stakeholders to assess an organization and make informed decisions. These decisions include whether or not to invest in, work for, buy from or supply to an organization and, in the case of voters, which political leaders to support. Disclosure is a key driver of stakeholder decision making and behaviour.

As climate change has become an increasingly important issue for many stakeholders, companies need to disclose information on how it affects them. Investors, shareholders, lenders, insurers, regulators, employees, consumers and voters increasingly want to know how these entities are managing climate-related risks and opportunities. Governments also need this information to facilitate the development of coherent and credible public policy.

Climate-related disclosure has the potential to improve the management of climate risks and opportunities, and to encourage informed investments in climate change adaptation and GHG emissions reduction by investors, businesses and governments. To support climate-risk management and investment decisions, transparency and timely access to information through disclosure are necessary.

A research report by Chartered Professional Accountants (CPA) Canada asked ten institutional investors, who hold approximately $1.9 trillion in assets under management, to identify the climate-related information that they use in decision making, how they use it and the impact that it has on decisions (CPA Canada, 2019a). The investors identified specific disclosures by companies that they considered important to their decision making, which included:

- the exposure of the organization's specific physical locations and infrastructure, including supply chains, to extreme weather events (e.g., floods, wildfires, ice storms, droughts, early thawing), potential impacts and how the organization is managing its exposure;
- water information where critical dependencies exist, including potential impacts of water deficiencies and the company's related risk management processes and plans; and
- trends and measures to reduce GHG emissions, including targets that are both absolute and intensity-based (CPA Canada, 2019a).

Investors also seek information on risks and opportunities associated with the transition to a low-carbon economy, as well as analyses of climate risks and opportunities for a company's medium- and long-term strategies. Climate-related financial disclosures are also important for lenders and insurers. Disclosures allow financial institutions to assess the resilience of the business models of companies that they serve and of their own business models to better manage their exposure to climate risk.

Ultimately, climate-related disclosure allows markets to better assess which entities can manage climate risks and seize related opportunities in a low-carbon economy, and to determine which entities are strategically resilient to the physical and transition risks associated with climate change. This, in turn, may encourage sustainable investment (Expert Panel on Sustainable Finance, 2019).

8.3.2 Mandatory disclosure in Canada

A publicly-traded company is required by provincial securities laws to disclose information regarding all material risks that it faces. Commitments, events, risks or uncertainties that the company reasonably believes will materially affect its future performance should be disclosed, as well as the company's policies and procedures related to risk management and oversight. There are no prescriptive reporting requirements in Canada pertaining specifically to climate change issues. The requirement to disclose is driven by materiality (i.e., the extent to which the risk is deemed material at the time when the disclosure is being made). Materiality (*see* Box 8.1) is assessed by reference to the "reasonable investor" standard. Information is likely to be material if a reasonable investor's decision about whether or not to buy, sell or hold the company's securities is likely to be influenced or changed if the information is omitted or misstated (Canadian Securities Administrators, 2019; 2010).

Box 8.1: Materiality

Some examples of climate-related risks that might be material to a company include:

- severe weather events or slow-onset events that might result in damage to assets, personal injury, operational disruptions, employee problems, or supply chain or customer distribution disruptions;
- climate-related regulations;
- reputational issues (including employees' and investors' attitudes); and
- business model or strategy changes relating, for example, to changes in demands for products or services, the availability of renewable energy or the development of energy-efficient products.

Such climate-related risks may result in financial impacts, including asset write-offs, capital expenditures, increased costs and reduced revenues (Canadian Securities Administrators, 2019).

For publicly-traded companies, the Canadian Securities Administrators (2019) have published several guidance materials, of which the most comprehensive is Staff Notice 51-358: Reporting of Climate Change-related Risks. This notice contains principles for issuers seeking to make materiality determinations and urges companies to err on the side of disclosure when in doubt.

The Canada Business Corporations Act and provincial corporations and securities legislation generally require companies to prepare financial statements in accordance with Generally Accepted Accounting Principles (GAAP). For publicly accountable enterprises in Canada, the International Financial Reporting Standards (IFRS) are the accounting standards used that represent GAAP. According to an article by a member of the International Accounting Standards Board, reporters under IFRS should take note that climate risk is addressed by existing requirements, even if not explicitly referenced (Anderson, 2019). As regulators and shareholders increasingly look for such disclosure, reporting entities may need to incorporate these risks into their financial statements.

The quality and quantity of climate-related disclosures have improved over time. A study of Canadian publicly-traded companies using data from annual reports prior to 2018 (before the release of the TCFD recommendations) found significant variation in whether companies made climate-related disclosures, as well as in the nature, amount and quality of the disclosures (Canadian Securities Administrators, 2018). This study found that climate-related disclosures were inconsistent and difficult to compare. In particular, the majority of climate-related disclosures did not include financial metrics or targets. As such, disclosures were not comparable across or within industries, and an inconsistent use of terminology contributed to the lack of comparability. A more recent study by CPA Canada, using 2018 data, found that TCFD-related disclosures have increased and that the amount and quality of disclosures are increasing, although the quality still varies (CPA Canada, 2020).

8.3.3 Voluntary disclosure

Increasingly, Canadian companies are voluntarily disclosing climate change information that they do not consider to be material for securities law. Some Canadian cities and municipal governments are also now producing voluntary climate-related reports. The practice of disclosing in voluntary reports benefits many stakeholders, including investors, employees, customers, suppliers, lenders, insurers, governments and rating services.

The framework proposed in the recommendations of the TCFD (*see* Box 8.2) was arguably the most common voluntary reporting framework used in Canada in 2020. It has been endorsed by the Government of Canada for Crown corporations, and is a condition for companies receiving COVID-19 financial support (Canada Enterprise Emergency Funding Corporation, 2020). The Expert Panel on Sustainable Finance recommended that all Canadian companies adopt this reporting framework.

Box 8.2: Recommendations of the Task Force on Climate-related Financial Disclosures (TCFD)

The TCFD recommended disclosures that are intended for voluntary use by organizations of all types in their mainstream financial filings (i.e., those filed with securities and/or industry regulators) (*see* Figure 8.2).

Figure 8.2: Core elements of recommended climate-related financial disclosures. Source: Adapted from Task Force on Climate-related Financial Disclosures, 2017.

The TCFD recommends that all organizations should, irrespective of materiality, disclose the governance and risk management elements. In addition, asset owners and asset managers should disclose carbon footprint information in reports to clients and beneficiaries, regardless of any assessment of materiality. If this information is assessed as material under the same criteria used in their regulatory filings, then organizations should also disclose the following elements: strategy, metrics and targets. Scope 1, 2 and 3 greenhouse gas (GHG) emissions and scenario analysis (i.e., the resilience of the organization's strategy under different climate change scenarios) are included as part of the metrics and target elements. Organizations omitting a recommended disclosure should disclose their rationale for doing so. The TCFD provides supplementary disclosure guidance for banks, insurance companies, asset owners and asset managers.

As of September 30, 2020, the TCFD framework was being used by all of the major Canadian banks and publicly-traded insurance companies, as well as by some other large Canadian publicly-traded companies. Many of these companies made disclosures in all categories, including nascent scenario analysis (CPA Canada, 2020). The TCFD framework has been endorsed by major accounting firms, CPA Canada and by Canadian pension plans and asset managers.

In its global status update report published in mid-2019, the TCFD (2019) noted that, in its view, while important progress in global climate-related disclosure is being made, more clarity is needed on the potential financial impacts of climate change. It also noted that disclosure is weak with respect to strategic resilience, which is of great interest to most capital providers. It concluded that adoption of the TCFD framework can be expected to widen and improve as the private sector refines the emerging good practice in efficient and decision-useful climate-related disclosure.

Another vehicle used for voluntary disclosure by companies, cities and regions in Canada and elsewhere is CDP (formerly Carbon Disclosure Project), which circulates and collates annual surveys on climate change and other issues (CDP, 2020). These surveys incorporate the TCFD disclosure elements and are a significant source of information for investors, customers, suppliers and governments. Over 250 Canadian companies reported in these surveys in 2019.

Some Canadian companies have also issued reports using the Sustainability Accounting Standards Board (SASB) framework, which incorporates climate change within a variety of other environmental, social and governance risks (Sustainability Accounting Standards Board, 2018). The SASB creates industry-specific sustainability accounting standards that help companies to identify and disclose material information on climate risks to investors in their mainstream financial filings. The Canadian Securities Administrators (2019) has suggested that Canadian issuers may wish to take note of SASB’s metrics in making decisions with respect to climate-related disclosure.

8.3.4 Emerging practices

For federal, provincial and municipal governments, disclosure of climate change-related issues is largely dependent on public-sector accounting standards that do little to specifically address climate-related issues. Additional disclosure is uncommon and has largely been driven by government leaders who voluntarily decide to provide such information. Fortunately, a number of large Canadian municipalities are demonstrating leadership in climate-related disclosure. The cities of Vancouver, Montréal and Toronto are all enhancing their disclosure on climate-related matters, and have worked with CPA Canada to develop guidance that can be used by municipalities across the country (CPA Canada, 2019d).

In its final report, the Expert Panel endorsed the TCFD framework with respect to both federal and provincial Crown corporations, as well as for private sector issuers of all sizes. The Panel recommended a two-phased approach to implementation over a five- to seven-year timeframe, depending on issuer size. It further recommended the implementation of TCFD, in close partnership with the provinces, under a mandatory “comply or explain” regime, which was one of the options that had been considered, but not adopted, by the Canadian Securities Administrators in its 2018 Report (Expert Panel on Sustainable Finance, 2019).

8.3.5 Opportunity for improvement: Data and methodology gaps

Studies on climate-related financial reporting have called for businesses, financial institutions and asset managers, along with their boards of directors, management and professional advisors, to become better educated with respect to the business risks and opportunities, as well as potential financial impacts of climate change (Canadian Securities Administrators, 2018). Multiple initiatives are under way in this regard, including training programs. In order for organizations to rigorously assess, manage and disclose their risks, there is a need for the development of new tools, models, methodologies and standards for physical and transitional climate risk analysis under different emissions scenarios, along with the expertise to use and interpret them. For policymakers, scenario analysis and stress-testing will be important for assessing whether financing flows are consistent with an orderly transition to a climate-resilient and low-carbon economy, and also for determining whether the financial system will be resilient to climate-related shocks.

For organizations conducting physical risk analyses, there are frequent limitations on the availability of relevant non-proprietary historical data or climate projection data for all locations of an organization’s assets, production, distribution and supply chain. In addition, the cost of employing the expertise to interpret or use that data for TCFD purposes can be prohibitive for many companies. Various initiatives at the federal, provincial and local levels are under way to provide broadly available access to complete, authoritative and decision-useful climate information and advice (Government of Canada, 2020; LAMPS, 2020; Pacific Climate Impacts Consortium, 2020).

The TCFD framework recommends that companies develop and disclose metrics and targets for assessing risks and opportunities, but it does not give specific guidance in this area. Companies and their boards of directors have struggled to obtain and analyze the information necessary to develop such metrics and targets (CPA Canada, 2019b, c). Companies within the same industry have often lacked information about what their peer group members are doing in this regard. To help alleviate this situation, the TCFD has committed to continuing to work with market participants to refine metrics so that they are consistent, comparable and decision-useful (Carney, 2019). Studies have also been published in Canada to provide companies and asset managers with industry- and sector-specific metrics to assess and quantify various risks (Feltmate et al., 2020).

There are significant methodology gaps associated with scenario and stress test analysis. The TCFD recommends using scenario and stress test analysis to, for example, create hypothetical constructs that yield a series of potential outcomes based on specific assumptions, factors and methodologies, such as the assumed global temperature rise, the energy mix, or whether the transition to a low-carbon economy happens smoothly or abruptly. Although some publicly available scenario models exist, there are many bespoke private models. As of September 30, 2020, there was a lack of guidelines, standards, protocols and consistent practices in this area (CPA Canada, 2019b, c). In most cases, organizations needed to seek outside expert assistance for this purpose. In 2019, the TCFD indicated that it was continuing to work with market participants to create "best practice" examples of scenario and stress test analysis. Furthermore, the United Nations Environment Programme Finance Initiative, the Network for Greening the Financial System and various organizations for Canadian pension funds, insurance companies, asset managers and financial institutions (all of which have Canadian participants) have continued to develop standard methodologies, tools and practices in this regard (Network for Greening the Financial System, 2020; UNEP Finance Initiative, 2019). The Expert Panel's Final Report recommended that the federal government sponsor a research effort to develop two or three base scenarios for climate-related disclosures for issuers and industry groups (Expert Panel on Sustainable Finance, 2019). Overall, it will take time for consistent practices to emerge and be adopted across all sectors of the Canadian economy.

8.4 Transitioning to a climate-resilient and low-carbon economy requires significant investments

There is a large financing gap for transitioning to a climate-resilient and low-carbon economy in Canada. Significant public and private capital are required to address this gap, but obstacles limit the opportunities to attract the appropriate amount of capital.

Canada has a large gap for financing the transition to a climate-resilient and low-carbon economy across economic sectors and assets owned by government, businesses, communities and individuals. The scale of the gap is beyond the capacity of the public sector alone and will require the mobilization of private capital. Financing both GHG emissions reduction and climate change adaptation with a more integrated approach is critical for transitioning to a climate-resilient and low-carbon economy. Reducing emissions is necessary to keep the cost of climate change adaptation under control. Climate risks (physical and transitional) and opportunities are increasingly being considered by investors in their investment strategies, portfolio planning and investments decisions. Financing mechanisms are being developed to address this gap, but they are currently limited in scale due to a number of obstacles.

8.4.1 Co-benefits of financing adaptation and GHG emissions reduction

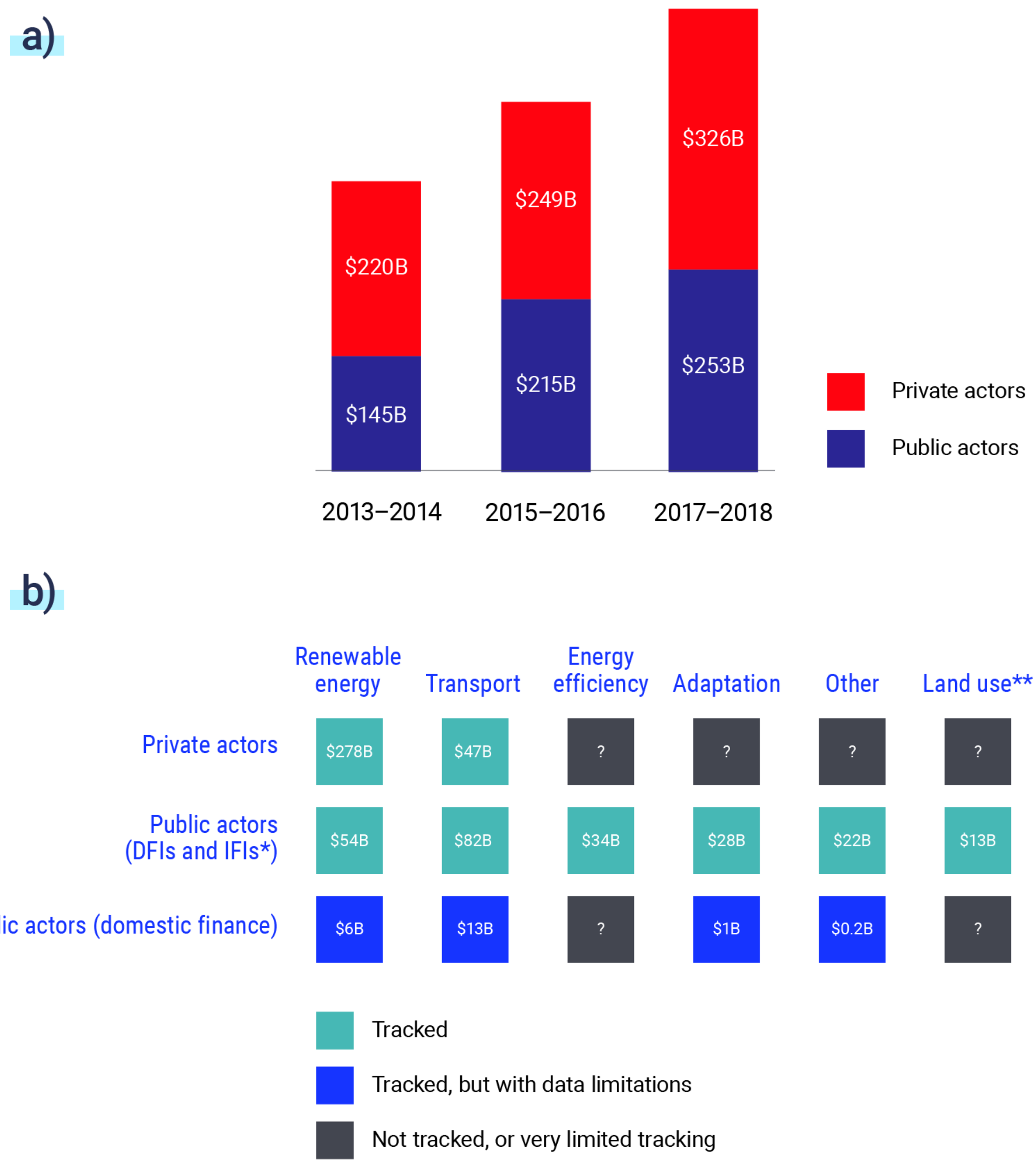
A climate-resilient and low-carbon framework for policy, planning and implementation can improve the cost-effectiveness of responses to climate change (Laukkonen et al., 2009; Yohe and Strzepek, 2007). The Intergovernmental Panel on Climate Change (IPCC) states with high confidence that, "[a] mix of [climate change] adaptation and mitigation options to limit global warming to 1.5°C, implemented in a participatory and integrated manner, can enable rapid, systemic transitions" (IPCC, 2019). Not considering adaptation and GHG emissions reduction together could be problematic for several reasons (Harford and Raftis, 2019). First, if considered separately, each may negatively affect the goal of the other. For example, developing a dense urban environment may reduce emissions by reducing the need for commuting, but it can increase the risk of urban flooding (Laukkonen et al., 2009). Secondly, there are numerous potential projects that can achieve both adaptation and GHG emissions reduction, and that may be overlooked if the goals are not considered concurrently. For example, infrastructure and buildings can be designed to have reduced energy requirements and be more resilient to weather-related extremes (Harford and Raftis, 2019).

In Canada, adaptation and GHG emissions reduction have traditionally been considered in silos. The Pan-Canadian Framework on Clean Growth and Climate Change provides a national framework for transitioning to a climate-resilient and low-carbon economy (Government of Canada, 2016), but it does not explicitly state the need to consider climate change adaptation and GHG emissions reduction jointly. Efforts are under way in Canada to move past the silo approach (Canadian Institute for Climate Choices, 2020).

8.4.2 Scope of transition

Significant investments are required for Canada to transition to a climate-resilient and low-carbon economy. A capital plan for implementing the Pan-Canadian Framework on Clean Growth and Climate Change, including an explicit analysis of investments needed in major sectors of the economy, would help to identify the size and scope of the market opportunity for financing the transition (Expert Panel on Sustainable Finance, 2019). The Insurance Bureau of Canada (IBC) has also recommended $5.3 billion of annual investments in adaptation measures to reduce exposure to physical climate-related risks (IBC, 2019a).

Globally, both the public and private sectors have been investing in such measures (*see* Figure 8.3). On average, total tracked public and private climate investments rose from $365 billion annually in 2013–2014 to $579 billion annually in 2017–2018 (Buchner et al., 2019). These investments included financing for renewable energy and transport, public financing for adaptation, public financing through development finance institutions and international finance flows for energy efficiency, land use and other climate change-related projects.



* DFIs = Development Finance Institutions, IFIs = International Finance Institutions
**Excludes amount allocated toward adaptation projects

Figure 8.3: Global tracked climate finance flows by private and public actors in billions of USD. a) Two-year averages of climate finance contributions by private actors vs. public actors during the period 2013–2018. b) Breakdown of the 2017–2018 two-year average climate finance by private actors vs. public actors, and by sector. Source: Adapted from Buchner et al., 2019.

8.4.3 Financing mechanisms for climate change adaptation and GHG emissions reduction

Beyond general debt and equity instruments, other financing instruments are being developed to raise funds for climate resilience and low-carbon projects. Some examples are highlighted below:

Green bonds: The proceeds of green bonds must be used for climate-related projects that reduce GHG emissions or improve climate resilience (Climate Bonds Initiative, 2020). Green bonds are increasingly used for integrated low-carbon and climate resilience projects. However, less than 5% of pre-2019 global green bond proceeds have funded climate change adaptation projects (Climate Bond Initiative, 2019). As of September 2020, technical criteria for adaptation-related projects, such as water and sewage infrastructure and climate-resilient infrastructure, are being developed for green bond (Climate Bonds Initiative, 2019).

Several provincial and municipal issuers of green bond list climate change adaptation and resilience as an eligible project category in their respective green bond frameworks. Examples include the Province of Ontario (n.d.), the Province of Quebec (Ministère des Finances du Québec, n.d.), the City of Vancouver (*see* Box 8.3; 2018) and the City of Ottawa (2020).

Box 8.3: Use of a green bond by the City of Vancouver for adaptation

The City of Vancouver issued its first green bond in September 2018, with a principal amount of $85 million. Proceeds from the bond are being used to fund up to seven types of projects: renewable energy, energy efficiency, green buildings, clean transportation, pollution prevention, sustainable water and wastewater systems, and the restoration, preservation and promotion of natural infrastructure and assets. Approved projects include upgrading sewer systems to eliminate sewage overflows, expanding the energy utility of the city's False Creek neighborhood, constructing more than 200 units of affordable housing and converting community buildings to net-zero buildings (City of Vancouver, 2018).

Sustainability bonds: Proceeds of sustainability bonds are exclusively applied to finance or re-finance a combination of "green" and social projects. In 2019, a number of Canadian financial institutions—including Sun Life Financial, the National Bank of Canada and BMO Financial Group—adopted sustainability bonds frameworks (Sun Life, 2019a; National Bank of Canada, 2018; Bank of Montreal, 2019a, respectively) and issued bonds (Sun Life, 2019b; National Bank of Canada, 2019; Bank of Montreal, 2019b, respectively).

Catastrophe bonds: With the rising impacts of extreme weather events, local, provincial and national governments need to manage their budgets to expedite recovery from disasters by covering damages and paying for the cost of reconstruction of public assets and infrastructure. Catastrophe bonds are designed to transfer these risks to capital markets. Catastrophe bonds serve as an insurance policy for the bond issuer, where the principal of the bond is forgiven when a disaster reaches a pre-agreed threshold. As of September 2018, the global catastrophe bond market stood at $30 billion, following a surge of issuance in 2017 and 2018 (Ralph, 2018). In Canada, insurance regulation guidelines issued in 2013 allow insurers to hedge risks using innovative financial instruments, but require prior approval for the instruments to contribute to capital requirements (Office of the Superintendent of Financial Institutions, 2013).

Forestry carbon offset credits: Several Canadian provincial carbon pricing regimes and standard-setters in the voluntary carbon markets have developed carbon offset protocols for Canadian forestry projects, with a number of projects in British Columbia. Although their primary goal is to reduce carbon emissions, these projects have co-benefits for climate resilience and physical climate risk reduction.

Transition bonds: Transition bonds are designed for carbon-intensive sectors, with proceeds used to finance new and/or existing projects for transition towards a reduced environmental impact, such as reduced carbon emissions (Takatsuki and Foll, 2019). These bonds are intended for companies and projects that would not qualify as "green." They may be particularly useful for Canadian firms in the mining, materials, and oil and gas industries (Riordan, 2020). There is some concern that companies may use these bonds to appear more environmentally friendly than they actually are (i.e., greenwashing). In Canada, Corporate Knights and the Council for Clean Capitalism released their Clean Transition Bonds Guideline, including the Clean Financing for Heavy Industry Taxonomy (Corporate Knights and the Council for Clean Capitalism, 2018).

Financing mechanisms for public assets and infrastructure projects: The Expert Panel on Sustainable Finance (2019) identified the need to develop a national Sustainable Infrastructure Plan, including projects and capital plans for public–private co-investment. The Panel emphasized the need for risk-based sustainability criteria to guide all new federal infrastructure planning, project selection and financing. It stressed that these criteria should include protocols to assess insurability earlier in the development process to ensure that infrastructure is sustainably designed and built, and that the risk could be transferred to insurers either directly or via insurance pools or capital market parametric structures (e.g., those used in catastrophe bonds) to reduce government liability as Canada's insurer of last resort (The Geneva Association, 2019).

Infrastructure financing mechanisms include:

- **Asset recycling:** Government assets with proven cash flows are sold to private investors to finance new projects. For example, the proceeds from the planned sale of the Trans Mountain Pipeline are committed to fund clean energy projects (Department of Finance Canada, 2019).
- **Resilience bonds:** A type of catastrophe bond that is designed to incentivize cities and other jurisdictions to invest in resilience. These bonds include a resilience rebate that converts avoided "measurable" losses from a risk-reduction plan into a revenue stream (Vaijhala and Rhodes, 2018). The European Bank for Reconstruction and Development issued the world's first dedicated climate resilience bond for $700 million USD (Bennett, 2019).
- **Private–public partnerships (PPPs)** have assumed a prominent role in infrastructure financing, although with continuing controversy over efficiency and costs (IBC, 2015; KPMG, 2015; Kunreuther, 2015). As of February 2020, there were roughly 286 active projects with a market value of $139 billion in Canada (The Canadian Council for Public-Private Partnerships, 2020).

- **The Canada Infrastructure Bank:** Established in 2017, the Canada Infrastructure Bank was tasked with investing $35 billion from the federal government in infrastructure projects with provincial, territorial, municipal and Indigenous partners, and with attracting institutional investors to fund new revenue-generating infrastructure projects that provide public benefits (Canada Infrastructure Bank, 2020). On October 1, 2020, Prime Minister Justin Trudeau and the Minister of Infrastructure and Communities announced a $10 billion growth plan over three years in partnership with Canada's Infrastructure Bank, targeting renewable energy projects, building retrofits, zero-emission busing and charging infrastructure, among other initiatives (Canada Infrastructure Bank, 2020).

8.4.4 Challenges for climate-related investing

Banks, institutional investors, insurers and pension funds are critical sources of investments in both adaptation and GHG emissions reduction projects, globally and in Canada. However, they face several obstacles to investing at the scale needed to transition to a climate-resilient and low-carbon economy (EU High-Level Expert Group on Sustainable Finance, 2018; The Geneva Association, 2018a). Some obstacles include:

- Political and public policy risks associated with the lack of national strategies, clear climate change policies, regulatory and legislative processes, and conflicting government subsidies;
- Need for a taxonomy and establishing “green” as an asset class to enable the development of a robust market and investable-grade, green investment opportunities;
- Need for data, tools, methodologies and expertise to assess risks and the quality of investments; and
- Regulatory issues related to higher capital charges associated with long-term, higher-risk investments.

Governments, policymakers and a variety of regulatory or standard-setting bodies play a key role in addressing some of these obstacles (The Geneva Association, 2018a), and the Expert Panel on Sustainable Finance (2019) addressed many of these issues in its recommendations.

A major challenge is presented by public policy and regulatory uncertainty. Investments in adaptation and GHG emissions reduction have long time horizons of years or decades, and regulatory uncertainty increases the riskiness of these investments (Expert Panel on Sustainable Finance, 2018). As of September 2020, there remained considerable international uncertainty concerning global GHG emission-reduction efforts, including international market mechanisms for trading emission reductions and carbon pricing. In Canada, the federal carbon pricing plan and related legislation endured repeated challenges from many provinces with three constitutional provincial reference cases, culminating in Supreme Court of Canada hearings (Rabson, 2020). Provincial planning to address climate change and reduce GHG emissions has changed significantly with the results of provincial elections.

A green taxonomy would provide common definitions for green, resilient and sustainable activities and investment practices. It could enable private capital to be directed towards such long-term activities, while preventing false claims and greenwashing. However, adopting an international taxonomy, such as the EU Taxonomy on Green Finance (EU Technical Expert Group on Sustainable Finance, 2020), as an authoritative framework can only partially address such obstacles, since international taxonomies may not fully apply to the Canadian economy (Expert Panel on Sustainable Finance, 2019). In 2019, a task group with the Canadian Standards Association was formed to develop a "transition" taxonomy for resource-heavy industries in Canada (Standards Council of Canada, 2019). This project builds on existing global frameworks and is being conducted in two parts, with part one focusing on the transition framework and definitions, and part two on a sector-specific transition taxonomy for seven priority sectors (Canadian Standards Authority Group, 2020).

Without accessible decision-relevant data on climate risks and opportunities, investors will not be able to assess the viability of their investments in climate change adaptation and GHG emissions reduction (Carney, 2019; Expert Panel on Sustainable Finance, 2018). Efforts to identify data needs and develop standard methodologies and tools for conducting climate change risk assessments are still in their infancy (Golnaraghi, 2019b). Furthermore, in-house expertise for producing, interpreting and utilizing climate-risk information is a challenge for both public and private sectors in Canada.

A significant amount of climate risk-related data is collected by various federal, provincial and municipal agencies, academia, centres of excellence, non-governmental agencies and the private sector. As of September 2020, this data is not compiled or readily available, and it may remain prohibitively costly for an individual company to collect and conduct quality assurance on the necessary data for risk modelling. Furthermore, translating this data into decision-relevant risk information for financing decisions requires sector-specific information and multidisciplinary expertise (Golnaraghi, 2019a).

Targeted initiatives, such as the Canadian Centre for Climate Information and Analytics (C3IA), recommended by the Expert Panel, would help inform data analysis and decision making in this area. Since the 1990s, the insurance industry globally has significantly invested in innovative methods to assess, price and manage physical climate risks. The industry has been using traditional catastrophe models and is working to enhance capacities for modelling the effects of climate change with a forward-looking approach (The Geneva Association, 2018b). Catastrophe models are primarily available through commercial risk modelling firms and insurance/reinsurance brokers, and some international (re)insurance companies have also developed their own internal models. These models could also inform lending and investing decisions for real estate and infrastructure portfolios (Cambridge Institute for Sustainability Leadership, 2019a, b).

A complex landscape of specialized private climate risk data start-ups and environmental fintech companies (i.e., companies that use technologies to provide financial services) are emerging in the U.S., Europe and Canada. These companies provide data and analytics to financial and insurance companies (Golnaraghi, 2019b). As of September 2020, physical and transition climate risk modelling tools provided by these commercial data providers remained fragmented by the type of risk, sector and decision applications. International rating agencies, such as Moody's Financial Services and S&P Global Services, are building internal climate risk modelling capabilities for their sovereign, municipal and company credit ratings (Flavelle, 2019).

8.5 Investments in climate risk reduction build resilience

Investments in disaster resilience have demonstrated their effectiveness for reducing exposure to physical climate risks. Opportunities exist for governments, businesses and individuals to improve their resilience to physical climate risks and break the trend of increasing loss and damage related to climate events.

Socioeconomic impacts of extreme weather events are on the rise in Canada due to the increasing concentration of people and assets in high-risk locations, current approaches to development planning and construction practices, and climate change. There is increasing awareness about significant benefits of investments in pre-disaster prevention and risk reduction. However, such ex-ante investments represent only a small fraction of the costs paid for post-disaster recovery.

8.5.1 Investments in climate resilience are cost-effective

Canada has experienced significant losses due to climate-related disasters. The Insurance Institute of Canada finds that, since the 1980s, climate-related damage claims paid by Canada's insurers have increased 20-fold after adjustment for inflation, doubling every five to 10 years (Insurance Institute of Canada, 2020). Insured losses for climate-related hazards have increased to an average of $1.9 billion per year from 2010 to 2019 (*see* Figure 8.4). The largest insured loss events in Canadian history include the 2016 Fort McMurray wildfire, the 2013 Calgary flood and the 1998 Quebec winter storm. Rising insured losses are attributed to increases in the quantity and value of exposed assets, the frequency and intensity of hazards and insurance coverage rates.[1]

Between 1970 and 2014, more than 76% of Canada's Disaster Financial Assistance Arrangements (DFAA) spending was flood-related (Moudrak and Feltmate, 2017). These costs increased from around $100 million annually two decades ago to $500 million in 2009–2010 and reached $2 billion in 2013–2014.

1 Insured loss figures are provided, despite changes in insurance coverage rates over time, as there is no consensus on the methodology for estimating direct economic losses of disasters, which makes these estimates difficult to compare.

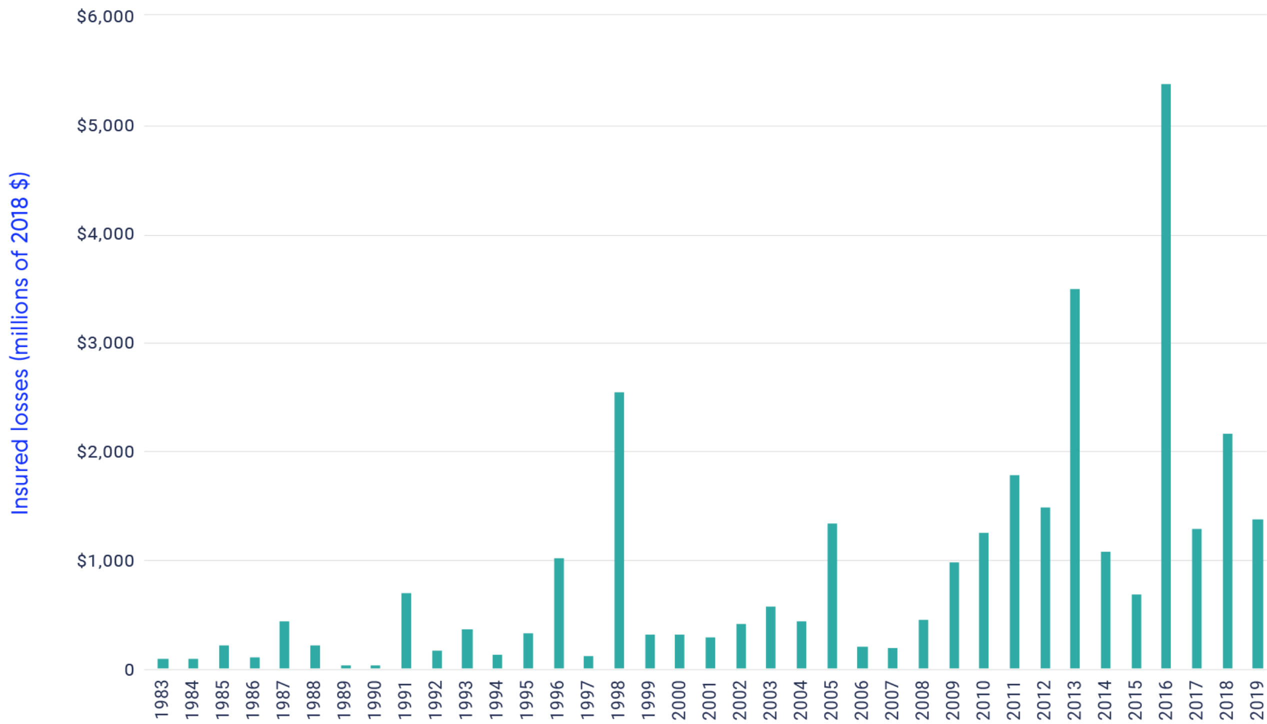


Figure 8.4: Annual insured losses related to natural hazards in Canada, in millions of 2018 $. Data source: CatIQ, n.d.; Insurance Bureau of Canada, 2020.

The physical effects of climate change are expected to increase losses in many ways. Physical climate risks can cause direct and indirect losses for governments, businesses and individuals (*see* Box 8.4).

Box 8.4: Physical climate risks for governments, businesses and individuals

Governments:

- Costs of emergency relief and response
- Costs of relocation of affected and at-risk populations
- Reconstruction costs
- Costs of rehabilitation and recovery
- Contingent liabilities for state-owned enterprises and enterprises critical to economic recovery

- Decreased tax revenues from business interruption
- Opportunity cost of diverting funds to reconstruction and recovery efforts
- Increased expenditures for social recovery programs
- Increased borrowing costs and potential negative impacts on the sovereign credit rating
- Migration of populations due to loss of livelihoods

Businesses:

- Disruptions to employees
- Loss of assets and inventory
- Reconstruction of assets
- Disruption to critical infrastructure needed for operations
- Disruption to supply chains
- Spillover effects from business interruptions
- Increased borrowing costs

Individuals:

- Loss or damage to homes, personal property and other assets
- Loss, damage or disruption to essential infrastructure (e.g., schools, hospitals, water and sewage management, transportation)
- Risks to food security and water safety
- Forced relocations and additional living expenses
- Mental health complications
- Loss of traditional knowledge due to loss of life and loss of livelihoods linked to Indigenous peoples' relationship with the land

Source: The Geneva Association, 2020

Overall, studies find that ex-ante investments in climate resilience could be cost-effective. The report of the Global Commission on Adaptation (2019) finds that investing $1.8 trillion globally from 2020 to 2030 in five areas to improve climate resilience could yield $7.1 trillion in net benefits. Studies in the U.S. and Canada show that, on average, investments in climate risk reduction can result in about four to twelve dollars saved for each dollar invested (Porter and Scawthorn, 2020; Porter et al., 2018).

8.5.2 Managing risks of climate-related extremes and related activities in Canada

8.5.2.1 Risk information

Investments in climate resilience are more effective if supported by decision-relevant climate risk assessment and risk pricing. Development of such information would require access to reliable hazard, exposure and vulnerability data, along with methodology and tools for combining this data to produce risk information (The Geneva Association, 2018b).

Since the late 1980s, catastrophe risk models have transformed insurance companies' capacities for pricing risks of extreme events such as floods, storms, hail and landslides, and for managing the property insurance business. These models are also increasingly being used by planning professionals, the financial sector and governments to understand the risk of natural hazards, and to conduct cost-benefit assessments for risk-reduction projects (The Geneva Association, 2018b). In Canada, the insurance industry subscribes to tools offered by commercial catastrophe modelling firms and (re)insurance brokers for major Canadian perils. Insurers complement this information by acquiring other data and investing in a variety of technologies (e.g., satellites) to enhance the quality of real-time risk information.

A 2014 IBC survey concluded that flood mapping in Canada was outdated and deeply fragmented. Since 2015, the IBC has been working with a number of commercial catastrophe risk modelling firms to produce flood hazard models and flood risk maps for Canada. These maps have been instrumental in supporting the National Working Group on Financial Risk of Flooding under the National Advisory Council on Flooding (ACF) with developing financial options for managing the flood-related costs of the highest-risk residential properties (IBC, 2019b; Canadian Intergovernmental Conference Secretariat, 2018). In 2015, the Government of Canada launched the National Disaster Mitigation Program, which created flood hazard mapping guidelines and funded mapping activities that adhered to these guidelines. The program also funded small-scale activities to reduce municipal flood risk. Increasingly, efforts are being made by various stakeholders, such as federal and provincial agencies and conservation authorities, to provide flood hazard mapping.

However, overland flood risk information is difficult for homeowners to obtain, and many flood maps remain outdated and fragmented (Adriano, 2019). Furthermore, a study involving five municipalities concluded that high-resolution cross-sectoral data would improve the quality of flood hazard maps, and would be needed to develop finer-resolution flood risk information to support risk management decisions at the municipal level (Canadian Water Network and IBC, 2019).

8.5.2.2 Risk reduction and prevention measures

Various risk-reduction strategies can be undertaken based on risk analysis. Examples include building climate resilient infrastructure, improving nature-based infrastructure as a buffer, adopting updated building codes, land-use planning and managd retreat away from high-risk areas. As of September 2020, no comprehensive

Canadian study of climate resilience measures existed, but smaller-scale studies have found significant benefits. Studies consistently identify significant opportunities to reduce disaster risk in a cost-effective manner. For example, a study of possible flood abatement strategies in the province of Quebec found "at least one adaptation measure is beneficial in comparison with non-intervention (net benefits greater than 0) in 76% of cases" (Circé et al., 2016). The ICLR study of the Climate Resilient Buildings and Core Public Infrastructure Initiative found that the program will provide $12 in benefits for every dollar invested (Porter and Scawthorn, 2020).

The National Working Group on Financial Risk of Flooding recommended a three-pronged approach to address flood risks (IBC, 2019b). This includes the following: elevating consumer and government awareness to incentivize active flood-risk reduction; producing or improving public-facing risk maps that allow insurers, as well as property owners and governments, to collaborate on identifying, updating and managing risks; and reducing the number of Canadians who live in areas at high risk of flooding by implementing flood risk reduction measures and strategic retreat from high-risk areas.

Natural infrastructure can be a cost-effective way to reduce financial losses that would otherwise result from flooding and to create a buffer for reducing the impacts of storms in coastal regions. For example, naturally occurring wetlands provide storm water storage, flood reduction, water quality improvement, carbon sequestration and other benefits (*see* Ecosystem Services chapter; Moudrak et al., 2018).

Updating and proper enforcement of building codes and standards have been highly effective for reducing disaster losses (Porter et al., 2018; Czajkowski et al., 2017). It takes time to develop, adopt and implement building codes for private and public buildings, homes and infrastructure. Canada's system includes a requirement to demonstrate that new approaches (such as updated codes) would result in savings that exceed costs over time. Many homes, buildings and infrastructure in Canada were designed and built based on codes established decades ago. While new construction must conform to regulatory requirements for new building codes, retrofitting existing structures is voluntary, unless required as part of securing a municipal building permit. Furthermore, the costs of retrofitting are often much higher than the cost of including climate resilience features in a new home.

In this regard, ICLR and its 120 member insurers provide homeowners with guidance for assessing the risk of damage and advice on how to retrofit existing structures to address most climate risks. Furthermore, with the increasing flood risks in Canada, efforts are under way through the ICCA to provide guidelines and standards for resilient communities (Moudrak and Feltmate, 2019a), commercial buildings (Moudrak and Feltmate, 2019b) and residential housing (Evans and Feltmate, 2019). The ICCA has developed formal flood protection training programs for home inspectors and insurance brokers to enable and expedite the adoption of flood protection measures (ICCA, n.d.). The insurance industry has also begun to offer reduced insurance premiums to homeowners who retrofit their homes against floods in some areas (Grzadkowska, 2019). Another example is The Atmospheric Fund, a non-profit created by the City of Toronto Council in 1991, which finances local initiatives to combat climate change and improve air quality in Toronto through a variety of programs, including retrofitting (The Atmospheric Fund, 2020).

Much of Canada's core public infrastructure is operating beyond its expected lifecycle and needs replacement or retrofitting (Canadian Infrastructure Report Card, 2019). The Government of Canada has launched initiatives to support investments in climate-resilient infrastructure, such as the Disaster Mitigation and Adaptation Fund (2018), a $2 billion program to support infrastructure projects that improve resilience against natural hazards (Infrastructure Canada, 2018). In 2019, the Government of Canada implemented the Climate Lens for infrastructure projects in certain programs, which requires project proponents to undertake a GHG emissions reduction and/or climate resilience assessment (Infrastructure Canada, 2019). Engineers Canada, with support from the Government of Canada, developed the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol, a popular tool that is now managed by the ICLR, the Climate Risk Institute and GIZ GmbH. There is a need, however, for more to be done in this area (Expert Panel on Sustainable Finance, 2019), and significant opportunities exist for improving the climate resilience of Canada's infrastructure.

Local governments are important leaders in the promotion of climate resilience. ICLR has published 60 case studies of local action in Canada consistent with best practices in climate resilience. The Institute's "Cities Adapt: Celebrating Local Leadership" case studies focused on extreme rainfall, extreme heat and extreme weather (Kovacs et al., 2018; Guilbault et al., 2016; Kovacs et al., 2014).

8.5.2.3 Reconstruction

Risk-informed land-use planning by local governments is another important tool for reducing risks related to climate change. This planning can take the form of re-zoning, banning new construction, home buyouts in high-risk zones, incentives to relocate existing assets to lower-risk zones and restoring natural infrastructure.

Reconstruction decisions after extreme events provide an opportunity to rebuild in more resilient ways. This includes rebuilding according to updated building codes and other climate resilience standards, and may even involve rebuilding in a lower-risk location. For example, following the spring 2019 floods, the Government of Canada and the Government of Quebec supported the relocation of homes from high-risk zones in the province of Quebec. The government offered building buybacks for residential homes, placed a limit on the DFAA payouts and encouraged private insurance markets to play a larger role (Blewett, 2019; Lau, 2019). However, some buyback programs have been subject to controversies (CBC News, 2019). Re-zoning could also be politically difficult after a disaster.

8.5.2.4 Early warning and emergency preparedness

Early warnings linked to emergency preparedness enable action to minimize injuries and loss of life through evacuations, proper sheltering and avoidance of the area at risk. They can also reduce damage to property by, for example, moving valuable assets to safer locations. Early warnings can also expedite response to, and recovery from, disaster events, activate business continuity plans and speed up insurance claim payments (Golnaraghi, 2012).

In Canada, various federal, provincial and territorial agencies are responsible for warnings for different hazards. Although the responsibility for early warning may rest with one organization, it is frequently supported by information provided by multiple organizations working across jurisdictional domains. This model works well only if there is a strong inter-agency coordination mechanism, particularly in relation to appropriate data sharing and data analytics platforms (Bednar et al., 2019, 2018).

Municipal and provincial authorities, in coordination with Public Safety Canada, are responsible for implementing emergency preparedness measures on the ground. A number of other stakeholders, such as the private sector, the media and community-based non-profit organizations, play a critical role in the dissemination of alerts and warning, raising awareness and promoting actions at the community level. Overall, there is significant room to enhance preparedness by using scientific advancements that would allow for a longer lead-time to anticipate and prepare for events and foster cooperation between agencies (Henstra and Thistlethwaite, 2017; Shrubsole et al., 2003).

8.5.2.5 Risk financing and risk transfer (insurance and alternative risk transfer)

A number of financial incentives, including insurance premium discounts and grants for climate resilience activities, can also encourage cost-effective investments in risk reduction (Porter et al., 2018; Multihazard Mitigation Council and Council on Finance, Insurance and Real Estate, 2015). Beyond incentivizing investments in climate resilience, disaster insurance coverage plays an important role in expediting recovery efforts to return communities to normalcy. Studies find that countries with lower insurance penetration experience larger declines in economic output and greater fiscal strain after a disaster than countries with higher insurance penetration (Wolfrom and Yokoi-Arai, 2016; von Peter et al., 2013). On average, disasters have no lasting impact on a fully insured economy, but generate a 2.5% cumulated loss in output over 10 years in uninsured economies (von Peter et al., 2013).

The insurance industry provides specialized risk transfer solutions to build financial resilience to impacts of extreme events such as floods, forest fires, severe wind and winter storms, to incentivize reduction of GHG emissions and to encourage entrepreneurship for green and clean technologies. In some regions of the world outside of Canada, the insurance industry is also providing innovative products to protect government budgets following disasters, including regional pools and disaster insurance (The Geneva Association, 2018a).

In Canada, insurance companies are active in a number of areas, including:

- Developing and offering a wide range of traditional and specialized products for protecting against extreme events such as storms, wildfires and floods; Green Building Restoration Insurance; and Green Construction coverage;
- Developing methods to improve insurance coverage;
- Offering insurance products with incentives for risk reduction and carbon footprint reduction;
- Launching centres of excellence on adaptation and investing in bilateral and multilateral research on climate change resilience and adaptation (such as the ICLR, the ICCA and Partners for Action);
- Sharing actionable guidelines on risk reduction and prevention for government, businesses, communities and householders based on their research;
- Investing in the latest technologies to enhance their capacities to expedite assessments and claim payouts after an event; and
- On the asset management side, Canadian life insurers are investing in bonds, which finance GHG emissions reduction and adaptation projects.

In Canada, the insurance industry is also actively engaging with the government at the federal, provincial and municipal levels to improve societal resilience to floods and wildfires, as well as exploring opportunities for public–private partnerships to enhance insurability and raise long-term capital for climate-resilient and low-carbon infrastructure. For example, through the National Working Group on Financial Risk of Flooding, the industry is sharing flood risk maps, providing guidelines for reducing flood risks, and developing solutions for managing the financial risk of flooding for high-risk residential homes (IBC, 2019b).

8.6 Climate litigation is increasing against governments in Canada

Climate change litigation is increasing against governments and their agencies in Canada. There is growing litigation seeking to compel or change governmental action, approvals or decisions, as well as lawsuits seeking financial compensation related to failure to adapt infrastructure.

Major court decisions in Canada and elsewhere have accepted the scientific evidence of anthropogenic climate change and associated physical risks. Some foreign courts have ruled in favour of climate plaintiffs to direct governments to take action on climate change mitigation or adaptation, and governments in Canada are facing similar strategic litigation. At the same time, interest groups (and some governments) have challenged the validity of climate-related laws, and are increasingly seeking judicial review or appeals of regulatory or administrative approvals granted for new projects or proposals that may increase downstream and upstream GHG emissions. Canadian plaintiffs have also increasingly sued for damages related to severe weather events and infrastructure failure. Governments and their agencies that own and operate infrastructure must manage potential liability related to failure to adapt infrastructure to climate change.

8.6.1 Introduction

Climate litigation is litigation in which climate change and its impacts are a key or major contributing consideration. It has proliferated globally, as is evident in the databases maintained by the Sabin Center for Climate Change Law at Columbia Law School and by the Grantham Research Institute on Climate Change and the Environment at the London School of Economics (these "Climate Databases" were last accessed on September 30, 2020). The majority of global climate litigation involves governments and their agencies as defendants, and litigation in Canada is no exception (*see* Figure 8.5).

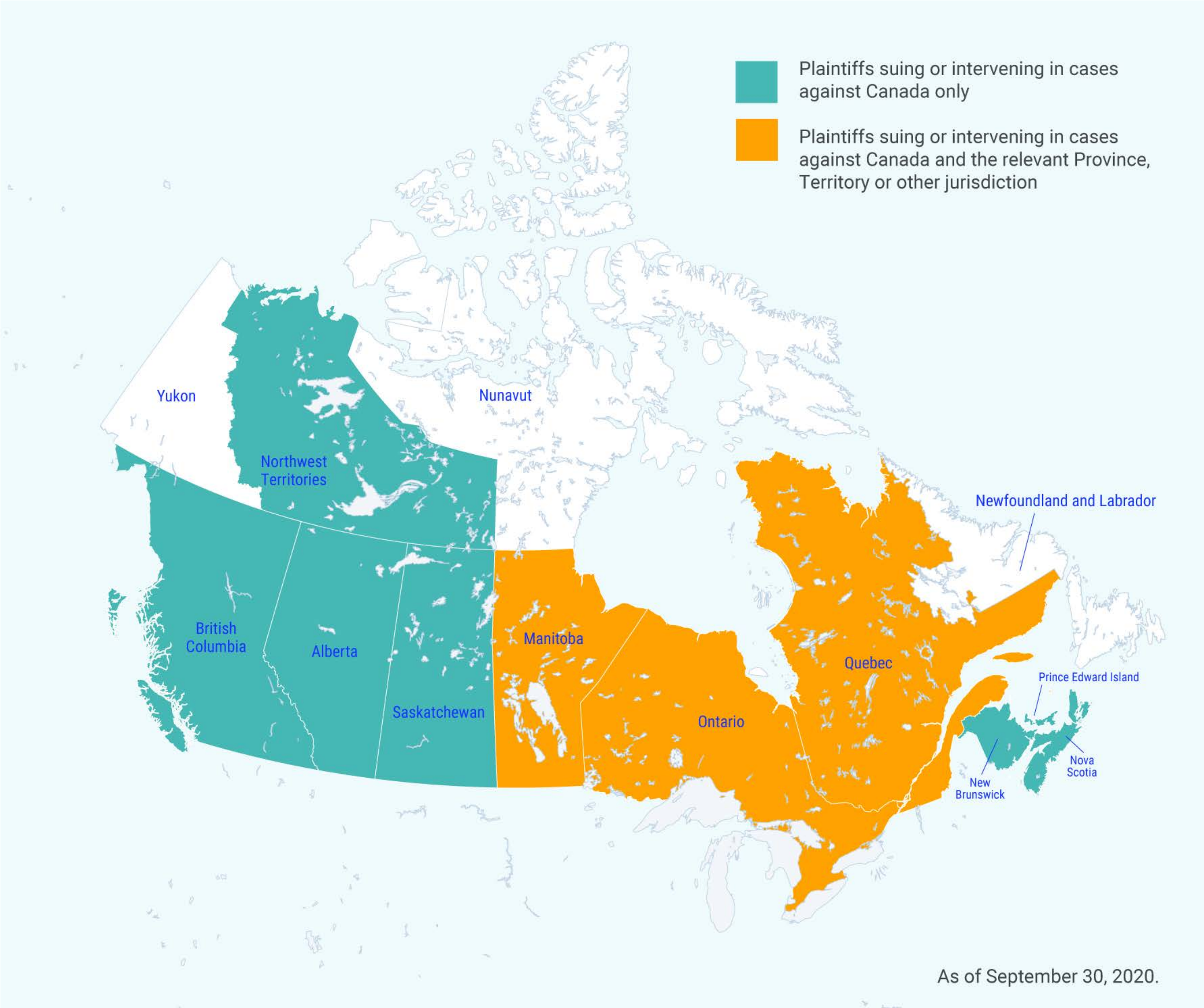


Figure 8.5: Canadian jurisdictions with ongoing climate litigation plaintiffs, as of September 30, 2020. Data source: Grantham Research Institute on Climate Change and the Environment, 2020; Sabin Center for Climate Change Law, 2020.

8.6.2 Litigation to compel government action

Strategic litigation intended to compel certain government actions has increased worldwide since a Dutch interest group won a decision in 2015 ordering the Dutch Government to increase its national emissions reduction target to be consistent with the IPCC's recommendations (Urgenda Foundation v. The State of Netherlands). The Dutch Court found that the state had a duty of care to its citizens to take climate change mitigation measures based on, among other things, the Dutch Constitution and the European Convention on Human Rights (to which the Netherlands is a signatory). This rights-based reasoning was echoed three months later in Pakistan when the Lahore High Court ordered Pakistan to implement the climate change adaptation plan that it had developed, ruling that a delay offended basic rights to life, human dignity, property and information under its Constitution (Leghari v. Federation of Pakistan).

Urgenda was upheld on appeal in 2018, and ultimately upheld by the Dutch Supreme Court in December 2019 (Urgenda Foundation v. The State of Netherlands). The Courts found that the Dutch Government owed a duty of care to its citizens under the right to life and the right to private and family life provisions of the European Convention on Human Rights. They concluded that the Dutch Government had a duty to take reasonable concrete actions in the face of the "real threat of dangerous climate change."

Spurred by these decisions, Canadian plaintiffs had launched four separate rights-based lawsuits as of September 30, 2020. Prior to 2018, there were only two Canadian cases in which courts were asked to review alleged climate change inaction on the part of the federal government. The first case (Friends of the Earth v. Governor General in Council of Canada) was in connection with alleged breaches of the Kyoto Protocol Implementation Act, and the second (Turp v. Minister of Justice and Attorney General of Canada) was related to the Government's decision to withdraw from the Kyoto Protocol. In the first case, the Court decided that the Kyoto legislation did not allow for substantive judicial review and did not create a mandatory duty to regulate. In *Turp*, the Court deemed that, in the absence of a challenge under the Canadian Charter of Rights and Freedoms, a decision made in the exercise of prerogative powers relating to international treaties was legislative in nature. Both cases reflected Canadian constitutional law principles whereby the making of laws, the exercise of a government's policy discretion embedded in laws and the repeal of laws are inherently political decisions (Hogg, 2007). Such decisions are generally protected from judicial review or from negligence claims by the principle of legislative immunity.

In November 2018, an interest group purporting to represent Quebec citizens aged 35 and under filed a class action lawsuit in Quebec against the Government of Canada (Environnement Jeunesse c. Procureur général du Canada). The claim sought a declaration that the Government's inaction on climate change had infringed their basic rights to "life, liberty and security of person" and to "equality" ("Charter rights") under both the Canadian Charter of Rights and Freedoms and the Quebec Charter of Human Rights and Freedoms, and infringed their "right to live in a healthful environment in which biodiversity is preserved" under the Quebec Charter. The claim also sought punitive damages. In July 2019, the Quebec Supreme Court ruled that the case was not properly framed as a class action; at the same time, however, it stated that the alleged violations of the Canadian and Quebec Charters were justiciable issues (i.e., not legislative or political).

Subsequently, a claim was brought by 15 youths in October 2019 in Federal Court alleging that the Government of Canada has caused, contributed to and allowed an unacceptably high level of GHG emissions; adopted, and then failed to meet, unacceptably low GHG emissions reductions targets; and actively facilitated industries and activities involving fossil fuels that emit a high level of GHG emissions incompatible with a stable climate system (La Rose et. al. v. Her Majesty the Queen). The plaintiffs claim that these alleged actions and inactions infringed their Charter rights and that the Government of Canada has a constitutional and common law obligation to protect the integrity of common natural resources that are fundamental to human life and liberty. The latter alleged obligation, known as the public trust doctrine, has not previously been formally applied by Canadian Courts (Burns Bog Conservation Society v. Canada). The plaintiffs are seeking that the Government acknowledge its obligations and "implement an enforceable climate recovery plan." In February 2020, the federal government filed its statement of defence in response to this claim which, among other things, cited and accepted the findings of Canada's Changing Climate Report. The federal government argued that the plaintiffs do not have sufficient connection to the issue to bring the claim, that the claims are not justiciable and that they do not give rise to valid causes of action under the Constitution or Charter rights or pursuant to common law.

An additional claim was brought in November 2019 by seven youths in the Ontario Superior Court. These plaintiffs allege that the Government of Ontario violated their Charter rights by abdicating its responsibility to address climate change. The plaintiffs are seeking, among other things, declarations that Ontario's current target violates the Charter rights of youth and future generations, and that the Canadian Charter of Rights includes the right to a stable climate system and an order requiring Ontario to adopt more aggressive emissions reduction targets (Mathur et al v. Her Majesty the Queen in Right of Ontario). In April 2020, the Government of Ontario responded by filing a notice of application to dismiss. The Government of Ontario argued that the plaintiffs do not have standing, that the issues raised and relief sought are not justiciable, that the Charter does not include the right to a stable climate system and that the allegations of harm are incapable of being proven.

In February 2020, two hereditary chiefs of the British Columbia Wet'suwet'en First Nation brought a representative action in Federal Court alleging that the Government of Canada's inaction on climate change, including its approval of GHG-emitting infrastructure projects, infringes their constituents' Charter rights and is in breach of the Government's duty under the Constitution Act to make laws for "peace, order, and good government" (Lho'imggin et al. v. Her Majesty the Queen). The plaintiffs are seeking an order requiring the Government to amend each of its environmental assessment statutes that apply to extant high GHG-emitting projects to allow project approval to be cancelled if Canada is unable to meet its Paris Agreement commitments or considers climate change to be a national emergency, as well as an order requiring the Government to complete an independent annual account of its cumulative GHG emissions in a format that allows assessment against its GHG reduction commitments.

8.6.3 Litigation seeking to change government actions, approvals or decisions

Canadian governments and their agencies have faced increasing litigation since 2015 related to approvals or permits granted for new infrastructure projects or proposals that may increase upstream or downstream GHG emissions. In 2015, an interest group challenged two permitting decisions regarding the proposed expansion of a coal handling and storage operation in British Columbia (Voters Taking Action on Climate Change v. Energy and Mines of British Columbia). The Court held that the group lacked standing. In another high-profile situation, some municipalities and interest groups sought judicial review of the 2016 approval of the Trans Mountain pipeline expansion, including, in one unsuccessful case, by asking that the National Energy Board consider the impacts of climate change in its assessment (Tsleil-Waututh Nation v. Attorney General of Canada). After the 2016 approval was quashed on other grounds in 2018 and the pipeline assets were sold to the federal government, a new approval was granted in June 2019. A number of groups sought judicial review of this decision, making climate change-related arguments, among others, but none of the climate-related claims were permitted to proceed to the Supreme Court of Canada. Climate-related arguments also surfaced in the approval process for the Coastal GasLink Project, and, in part, prompted *Lho'imggin* (Lho'imggin et al. v. Her Majesty the Queen). Similar concerns led to an application launched in May 2020 for judicial review of a regional assessment on the impacts of exploratory drilling off the coast of Newfoundland and Labrador, which was relied on by the Impact Assessment Agency of Canada (*Sierra Club Canada Foundation v. Canada (Environment and Climate Change Canada)*).

In another case seeking to change a government decision, an interest group filed an application alleging that the Government of Ontario failed to consult the public under Ontario's Environmental Bill of Rights when it revoked the regulations under Ontario's cap and trade program in 2018. The Superior Court of Ontario held in 2019 that the failure to consult was illegal (Greenpeace Canada v. Minister of the Environment, Conservation and Parks), but did not mandate remedial action.

Parties that are unhappy with the consequences of new climate-related laws and regulations have also brought litigation to challenge them. Syncrude Canada unsuccessfully challenged the validity of the Renewable Fuels Regulations under the Canadian Environmental Protection Act (Syncrude Canada Ltd. v. Attorney General of Canada). The purpose of the regulations, which prescribed that a certain percentage of diesel fuels must be renewable fuel, was to reduce GHG emissions. More recently, certain provinces challenged federal climate legislation through constitutional references in relation to the federal carbon pricing scheme, including the carbon tax and backstop GHG emissions pricing legislation. There were three provincial Court of Appeal decisions. The majority of the Court in both Saskatchewan and Ontario, for slightly different reasons, favoured the constitutionality of the legislation. The majority of the Court of Appeal in Alberta found to the contrary. Ultimately, the decisions were appealed to the Supreme Court of Canada. All of the Appeal Court decisions expressly accepted the serious issue of anthropogenic climate change in Canada, physical risk and the need for immediate action to control climate change risk (Reference re Greenhouse Gas Pollution Pricing Act, 2019 SKCA 40; Reference re Greenhouse Gas Pollution Pricing Act, 2019 ONCA 544; Reference re Greenhouse Gas Pollution Pricing Act, 2019 ABCA 283).

8.6.4 Litigation relating to failure to adapt infrastructure

Litigation is increasingly seen in Canada and elsewhere (Adler, 2018; Gundlach and Klein, 2018; Moran and Mihaly, 2018; Mahony, 2020) relating to failure to adapt infrastructure to increasingly foreseeable physical risks and impacts of climate change. Flood-related lawsuits against Canadian provinces, municipalities, watershed managers (e.g., conservation authorities) and others are on the rise (Moudrak and Feltmate, 2019a). These include class actions brought against the cities of Thunder Bay and Stratford, ON, alleging negligence in connection with the design, construction, inspection, maintenance and repair of storm water and sewage facilities, and against the Governments of Manitoba and Ontario, alleging negligence and nuisance in connection with water control structure management (Moudrak and Feltmate, 2019a). Class action and individual lawsuits were also brought in Quebec against several municipalities and the Government of Quebec, alleging negligence in connection with the 2017 and 2019 spring floods in the province (Richard Lauzon c. Muncipalité Régionale du Comté (MRC) de Deux-Montagnes, Ville de Sainte-Marthe-sur-le-lac, Procureur Général du Québec).

Lawsuits of these types in Canada and elsewhere are drawing increasingly on advancements in climate change attribution science (Burger et al., 2020; Setzer and Vanhala, 2019; Marjanac and Patton, 2018). With the changing climate, more frequent and severe weather events in Canada (Zhang, et al. 2019) could foreseeably stress or damage infrastructure and shorten its anticipated useful life. An Ontario Court, for example, found that the risks of potholes and road washouts were heightened by freeze/thaw cycles and heavy rainfall (Bishop v. Regional Municipality of Durham). Impacts from incremental, slow-onset or chronic climate-related events may do the same. There may also be cascading and cumulative effects. This creates the potential for personal injury, health and property damage. Injured parties who do not have insurance coverage or access to disaster relief or special compensatory funds may bring lawsuits seeking financial compensation (i.e., damages) under common law principles of negligence or nuisance.

In a negligence claim, the plaintiff must establish, among other things, that the defendant owed the injured party a duty of care and committed an act or an omission that breached a reasonable standard of care (i.e., that it should have foreseen the effects of climate change with respect to infrastructure and made appropriate decisions, but did not do so). A duty of care by a government may be established by a statute, and the statute might also create a right to damages for anyone injured. For example, municipal legislation in some provinces establishes a duty of care and a statutory right to damages in connection with the maintenance of roads. If the statute does not create an express duty of care, the context will be examined to see if a prima facie duty of care can be established. If it can, this duty will generally be upheld if the government's decision(s) relating to the infrastructure are operational decisions and not policy decisions, which are protected by the legislative immunity principle (Cooper v. Hobart). The line between policy decisions and operational decisions is not always clear; in common law, however, obligations to maintain infrastructure in a specific manner, to effect repairs or to perform regular inspections may be considered to be operational. In contrast, decisions to build new infrastructure as part of adaptation planning—where social, economic and political factors are at play—will likely be considered as policy decisions. The line between these types of decisions may also be modified by statute (e.g., Crown Liability and Proceedings Act, 2019, SO 2019, c 7, Sch 17). A nuisance claim against a government requires the plaintiff to show that owned or operated infrastructure (e.g., dams and other water-control structures) caused actual physical damage to another party's land, or substantially and unreasonably interfered with the use of that land (Anderson v. Manitoba). If the nuisance affects the public, such as blocking a public highway, it may be termed a public nuisance (Linden and Feldthusen, 2007). In a nuisance claim, it is not relevant whether actions or decisions with respect to the infrastructure are policy or operational.

A government may have a defence against a negligence or nuisance claim if a relevant statute clearly limits or excludes government liability in the circumstances. Some provincial and municipal laws provide such defences. For example, legislation in some provinces provides that a municipality cannot be found liable for nuisance, generally or for specific types of events that could be classified as nuisance (i.e., flooding) (e.g., The Municipal Act, S.O. 2001.c.25, s. 449(1) and the Local Government Act, RSBC 2015, c.1, s. 744). There may also be a "statutory authority" defence if the damage causing the claim is the inevitable consequence of carrying out an undertaking under statutory authority. Ultimately, where a government wishes to limit its liability (and, in the case of a province, that of its municipalities) with respect to common law claims (e.g., overland flooding), it can enact or amend legislation to this effect. For example, the Government of Ontario amended the Municipal Act (Ontario) to exclude liability for nuisance related to the escape of water or sewage from sewage or water works.

The concept of building climate resilience through infrastructure is nevertheless an important pillar of adaptation. Ultimately, litigation risk in this context should be seen as a driver of climate change adaptation.

8.7 Climate litigation against the private sector is a potential risk

While there has been virtually no climate litigation in Canada against private sector companies, Canadian companies are increasingly assessing potential climate litigation risks.

Potential litigation risks for the private sector stem from failing to properly disclose climate change-related risks, failing to adapt infrastructure in light of physical risks and, in some cases, for allegedly contributing to climate change and related damage. Litigation risks of this nature have become well known as a result of litigation in the United States and elsewhere. Litigation, even if unsuccessful against a company, may be extremely costly to the company and its insurers, may have significant reputational implications and could potentially impact the company's access to capital. Boards and senior management responsible for risk management are increasingly considering climate-related litigation as a component of that risk.

8.7.1 Potential for disclosure liability

Publicly traded companies may incur liability under applicable securities laws in relation to the disclosure or non-disclosure of material risks, including climate change-related risks (Canadian Securities Administrators, 2018). These (non-)disclosures may include physical and transition risks, their financial impacts and steps taken to mitigate or adapt to them (Canadian Securities Administrators, 2019).

Canadian securities regulators have a wide variety of powers to prosecute companies, their directors and responsible officers for disclosure offences. Such offences may include breaches of the rules requiring disclosure of material information in continuous disclosure documents (such as management's discussion and analysis, or annual information forms). More broadly, these also include cases where offering documents, financial statements or continuous disclosure documents contain statements that are misleading or untrue, or do not state a fact that is required to be stated or that is necessary to ensure that the statements are not misleading (e.g., Securities Act, R.S.O. 1990, c. S5, as amended, ["OSA"] Part XXII). These statements are judged according to the standard of materiality at the time and in light of the circumstances in which the statements were made. Securities regulators and Canadian courts usually apply the "reasonable investor standard"—information would likely be considered material if a reasonable investor's decision about whether or not to buy, hold or sell securities is likely to be influenced or changed if the information is omitted or misstated (e.g., OSA, Form 51-102 F2 at Part (1) e.).

Issuers and their directors and responsible officers may also be sued by investors for damages under the civil liability provisions of provincial securities laws (e.g., OSA, Part XXIII). This may occur if investors purchase securities in an offering in which the offering document contains a "misrepresentation." It may also occur where investors buy or sell already issued securities in the secondary market (i.e., through a stock exchange) if, at the time of their purchase or sale, either 1) the company has failed to disclose a "material change" in its business, operations or capital in compliance with securities laws; or 2) its continuous disclosure documents, other documents made generally available to investors (including website disclosures, corporate responsibility, climate resilience or sustainability reports) or public oral statements made on behalf of the company (i.e., by management or directors) contain a "misrepresentation". A "misrepresentation" is an untrue statement of a "material fact" or an omission to state a "material fact" that is required to be stated or that is necessary to ensure that a statement is not misleading in light of the circumstances in which it was made. Whether a change or a fact is "material" is measured by a "market impact" test: would that change or fact reasonably be expected to have a significant effect on the market price or value of the relevant securities? The answer to the legal question regarding what climate change-related information may be material for a "reasonable investor" or constitute a "material fact" is likely evolving, and will continue to do so as climate change impacts evolve.

As of September 30, 2020, no climate-related disclosure lawsuits had emerged against issuers in Canada, but the possibility of such claims was the subject of academic comment (Sarra and Williams, 2018; Williams and Routliff, 2017). In their analyses, the authors identified potential types of disclosure claims that might surface in Canada: failure to discuss financially material risks of the transition to low-carbon strategies (included as required by regulatory and societal factors); material misstatements of the value of a company's assets in light of "stranded assets" (i.e., those too costly to develop or operate) and unburnable carbon; or material misstatements relating to the risks of continued extraction and use of a high-carbon product, such as oil, gas or coal.

Outside of Canada, lawsuits alleging failure to disclose and misstatements have been brought in Australia and the United States. In several lawsuits against Exxon Mobil Corporation in the U.S., for example, it has been alleged that Exxon made material misrepresentations in its continuous disclosure documents about how it managed the risks of climate change in its investments and operations. The first such high-profile case (People of the State of New York v. Exxon Mobil Corporation), which focused on the period 2013–2016, was decided in Exxon's favour in December 2019. The New York Supreme Court determined, on the specific facts before it, that there was no proof of material misrepresentations (determined with respect to the "reasonable investor" standard under U.S. securities laws, which is similar to that in Canada) and there was no evidence that the impugned disclosure had any market impact. The decision was not appealed. Some actions have been brought in connection with disclosure of physical risk: for example, against electrical utility companies in California and their underwriters. There, investors alleged misrepresentation of the companies' exposure to wildfires, including the steps taken to improve and maintain infrastructure in light of known climate change conditions and related wildfire risks (York County v. Rambo; Barnes v. Edison International).

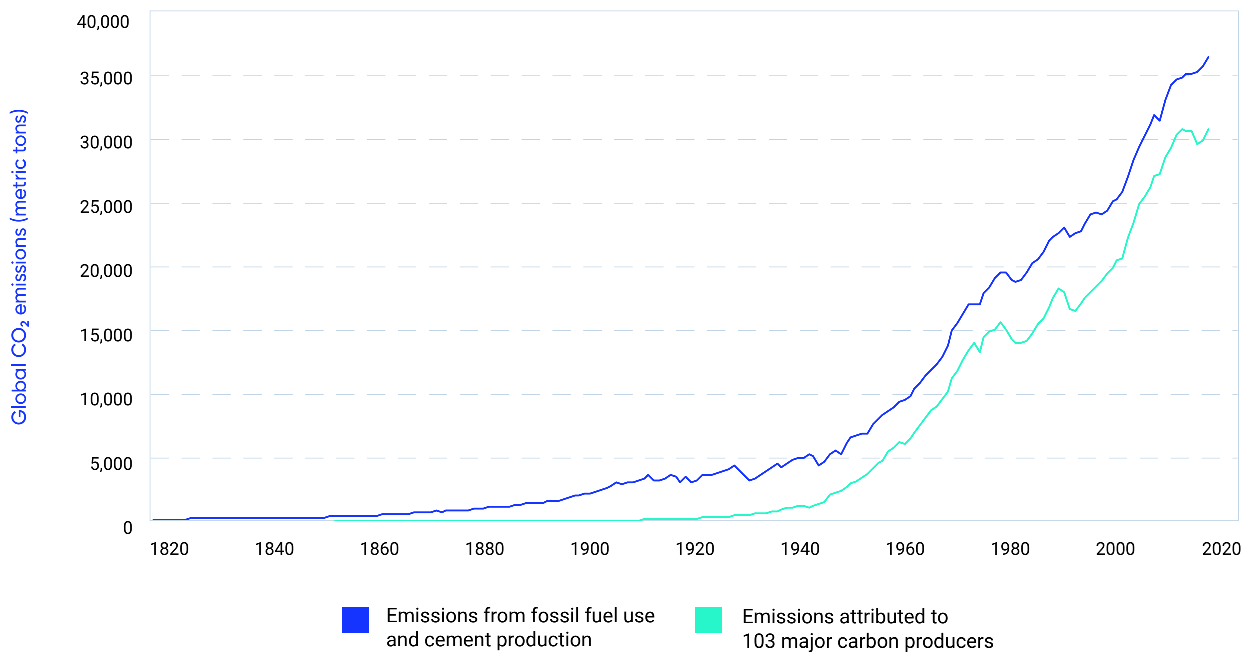
8.7.2 Potential for litigation related to failure to adapt infrastructure

For companies, professional firms and individuals that develop, design, build, own, operate, maintain or repair infrastructure, there are climate change-related litigation risks to adapt infrastructure, similar to the risks described earlier in this chapter for government infrastructure owners and operators. The risk of negligence or nuisance litigation against private sector actors is higher, however, than it is for governments, as there is no corresponding immunity principle and there are rarely statutory limitations of liability for the private sector. Infrastructure owners and design professionals are increasingly limiting legal and physical risks to their facilities by planning for impacts of climate change over the lifetime of their facilities, including by conducting climate vulnerability assessments and selecting design features, alternatives, site location and risk reduction measures accordingly (Goldstein et al., 2019; Adler, 2018; Gundlach and Klein, 2018).

8.7.3 Litigation alleging corporate responsibility for climate change

For companies operating in energy or resource sectors, an important trend is the increasing number of lawsuits worldwide against major carbon producers seeking to hold them liable for their alleged responsibility for climate change. This trend began following a study by Richard Heede (2014) that mapped and quantified the cumulative emissions of the 90 largest carbon producers from 1854 to 2010—dubbed the "Carbon Majors". The study was developed for lawyers seeking to legally establish a causal link between corporate activity and climate change (Setzer and Vanhala, 2019). It was used to launch a seminal case against a major German electricity producer in 2015 (Lliuya v. RWE AG), which is ongoing. The cumulative emissions results are updated annually (*see* Figure 8.6; Climate Accountability Institute, 2019), and researchers are collaborating with Heede to combine this work with extreme weather event attribution science (Ekwurzel, et al. 2017).

a)



b)

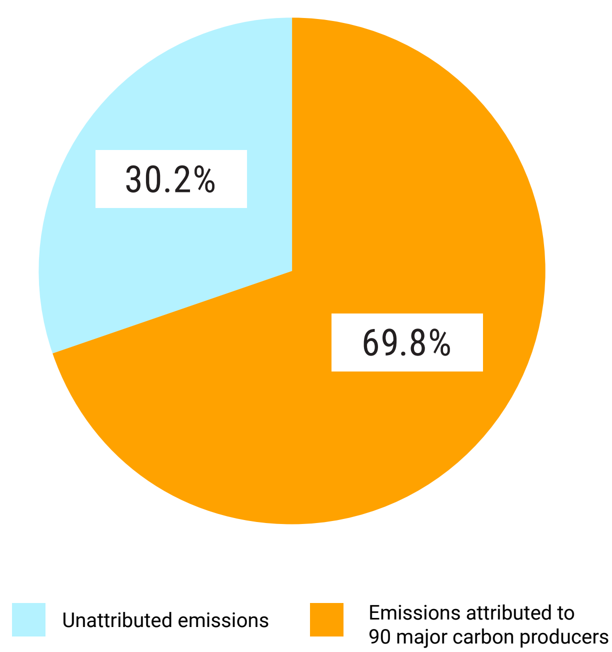


Figure 8.6: a) Annual global CO_2 emissions related to fossil fuel use and cement production for the period 1810–2017 (dark blue) and attributed to 103 major carbon producers (light blue). b) Percentage of global CO_2 emissions for the period 1751–2017 produced by major carbon producers (orange) vs. unattributed emissions (light blue). Source: Adapted from Climate Accountability Institute, 2019.

In the United States, in particular, a significant number of cases were filed in 2017 and 2018 by major cities, counties, one state (Rhode Island) and the largest association of fishermen on the West Coast against a long list of oil, natural gas and coal companies (including Canada's Suncor, Inc.). In 2020, during the period up to September 30, the states of Minnesota, Delaware and Connecticut, the county of Maui, and the cities of Honolulu, Washington, D.C., Hoboken, NJ, and Charleston, SC, all brought similar complaints. In these lawsuits, the plaintiffs are seeking damages to fund adaptation and repairs (i.e., massive infrastructure investments) for dealing with present and future damages from climate change. The plaintiffs have brought various types of claims under U.S. laws, including nuisance (public and private) and negligence claims, which are similar to Canadian laws. In the nuisance claims, climate change is alleged to be the nuisance and GHG emissions are alleged contributions to the nuisance. These U.S. lawsuits are being vigorously defended. Most raise complicated federal and state jurisdictional and procedural issues. The plaintiffs face significant legal issues, including the following: the American political question doctrine (which essentially says that political issues are non-justiciable), proof of causation (i.e., the link between the defendants' behaviour and the alleged harm suffered by the plaintiffs) and standing.

In December 2019, the Philippines Human Rights Commission announced the completion of its well-publicized three-year investigation into whether 47 of the world's largest fossil fuel firms—all Carbon Majors—could be held accountable for violating the rights of its citizens because of the damage caused by climate change. The Commission concluded that these companies played a clear role in anthropogenic climate change and could be held legally liable for its impacts in certain circumstances under Philippines civil law (In Re Greenpeace Southeast Asia and Others).

As of September 30, 2020, there were no Canadian lawsuits alleging corporate responsibility for climate change. Several municipalities in British Columbia had announced in 2019 that they were considering class action litigation against fossil fuel companies (Poggio, 2019), but had not proceeded. The City of Toronto indicated in 2019 that it was exploring litigation strategies. If a corporate responsibility case is brought in Canada, the analysis of the Philippines Human Rights Commission could be of interest to the court. Similarly, if a U.S. case is successful on the basis of legal principles similar to those in Canada, courts in Canada could be influenced by that reasoning and analysis.

8.8 Moving forward

8.8.1 Knowledge gaps

Climate-related disclosures, litigation and finance are important issues in the Canadian discussion about climate change. As of September 2020, a large number of Canadian companies and some municipalities are making climate-related disclosures, but the amount and quality may not meet the needs of stakeholders. A critical knowledge gap for investors in public companies is the lack of disclosure on the financial impact of climate change on companies and whether their strategies are resilient to climate-related risks. Currently, disclosure of material risks is mandatory for these companies, but there are no mandatory prescriptive requirements for the disclosure of climate-related risks and opportunities. Research could focus on assessing whether investor pressure alone may be insufficient to encourage greater disclosure of these risks and opportunities.

There are a number of gaps related to the financing of climate resilience and the transition to a low-carbon economy. The report of the Expert Panel on Sustainable Finance (2019) outlines a number of these gaps. There is preliminary evidence that some types of "green" finance are effective at encouraging investment in "green" projects, and taxonomies and information services are being developed to support such investments. However, it is still uncertain what combination of financial instruments and institutional supports will be required to significantly increase investments in climate resilience and low-carbon projects. With regard to investments in climate resilience specifically, evidence shows that such projects are often cost-effective, but it is unclear what measures are needed to encourage homeowners, business owners and owners of critical infrastructure to undertake them.

Climate-related litigation is increasingly occurring in Canada. Many important issues have yet to be finally decided. It is important that Canadian decision makers remain aware of the possibility of further climate litigation on climate-related matters, as virtually any legal issue related to climate change is a possible subject for litigation.

8.9 Conclusion

Climate change and the impact of extreme events are important issues for many decision makers in the public and private sector. The public policy conversation is framed around the need to reduce GHG emissions and the need to adapt to minimize the adverse impacts of climate change. The conversation in the private sector is generally framed around managing physical and transitional climate-related risks. This framing of the issue presents climate change as a relevant and urgent concern for a wide range of stakeholders, and may encourage both private and public entities to take additional measures to adapt to climate change.

The recommendations of the TFCD have emerged as the key framework for disclosure of climate risks. Their adoption by Canadian companies in financial and non-financial sectors, and by governments is growing and the recommendations are widely endorsed by stakeholders. Over time, investors and regulators are expected to apply increasing pressure on companies and governments in Canada to disclose climate-related physical and transition risks, as well as implement other elements of TCFD, a process that will increase information for markets and society about specific adaptation actions that they may take.

There has been a significant increase in the Canadian and international conversation about climate finance. Insurance companies and governments finance most of the recovery and repair costs of physical damage following extreme events. These costs have risen and are projected to continue to rise. Significant funds are also required from public and private investors to support the transition to a climate-resilient and low-carbon economy. As such, climate-related risks and opportunities are especially relevant for financial institutions. Pension funds, banks, governments and other investors are developing their understanding and management of the risks and opportunities involved in investing in initiatives related to, and affected by, climate change. Furthermore, several obstacles to investing at scale towards a climate-resilient and low-carbon economy need to be addressed, including political, policy and regulatory risks, the lack of a green taxonomy and the lack of accessible decision-relevant data.

Private investors are developing models and other tools to assess and manage climate-related risks and opportunities. This includes physical and transitional risks. The objective is to better manage climate risks as a business issue. These tools can be applied to any industry, but the focus of several current efforts is on supporting decision makers in financial institutions and regulators. Also, industry-specific tools and practices are being developed for major emitters and energy users. Access to relevant data and better organization-specific information about physical risks is expected to encourage greater action to increase resilience to climate extremes.

Investing in climate resilience could be cost-effective, and opportunities exist for governments, businesses and individuals to improve their resilience to physical climate risks. This involves scaling up investments and fostering stronger cooperation to enhance risk information and awareness, risk reduction and prevention, climate-resilient reconstruction, early warning and preparedness, and risk financing and risk transfer (including insurance) measures.

Climate-related legal action in Canada has significantly increased, directed primarily at governments. There are several legal initiatives seeking to force the federal and provincial governments to act on climate change based on alleged constitutional and common law rights. Interest groups and governments themselves are increasingly litigating against governments at various levels regarding policies and decisions in the planning context related to the transition to a climate-resilient and low-carbon economy. Litigation will remain an important tool to effect changes in policies and decisions. Legal action is also increasing against governments in connection with infrastructure failure resulting from severe weather events. In the absence of insurance coverage or disaster recovery funds for those harmed, and where there are no relevant statutory immunity provisions, the number of such claims may increase as severe weather increases.

Legal action is increasingly also being brought against private actors in connection with severe weather events and infrastructure damage. Outside of Canada, many lawsuits have been directed at private organizations alleging a causal connection between their GHG emissions and climate-related harm. Many such cases are ongoing in the United States, and one international proceeding recently found 47 Carbon Majors responsible for the consequences of their emissions. It is possible that similar Canadian lawsuits could emerge. If international trends are any guide, it is also possible that civil liability actions may arise in Canada based on climate-related disclosure issues under provincial securities laws.

Disclosure, the development of sustainable finance and climate litigation have the potential to encourage adaptation to climate change. Disclosure helps businesses and governments to better understand their climate-related risks and opportunities, and to make business decisions that will ultimately support the transition to a climate-resilient and low-carbon economy. Investors can use this information to reward companies and regions that act to reduce their risks and take advantage of opportunities. Adaptation measures can be highly cost-effective in preventing future losses. Both private and public sources of funding will be required to finance these cost-saving measures. The potential for legal liability for failing to assess and disclose climate change-related risks, for failing to adapt or for mismanaging adaptation are concerns for governments at all levels and for businesses.

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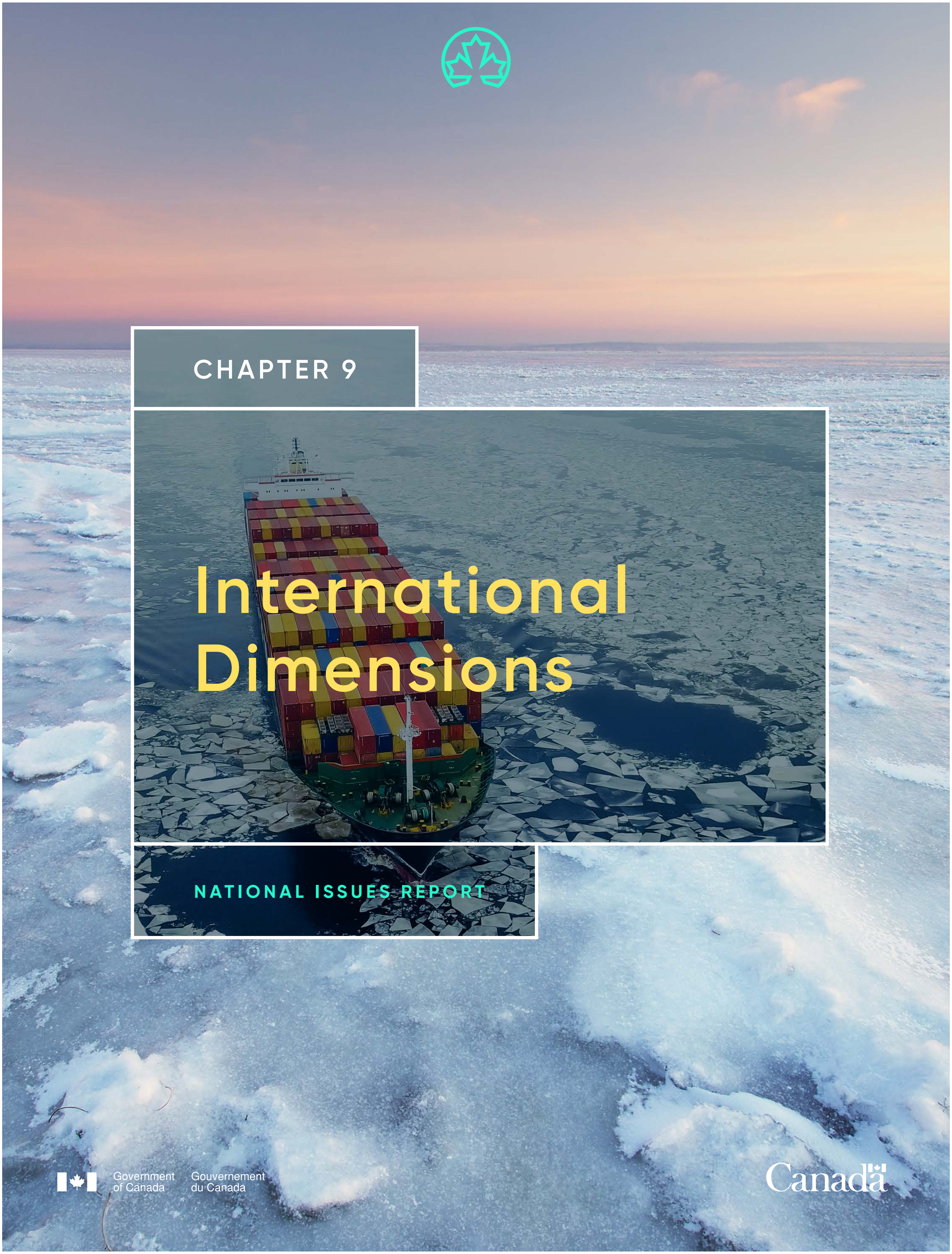

CHAPTER 9

International Dimensions

NATIONAL ISSUES REPORT

Government of Canada / Gouvernement du Canada

Canada

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Key messages

Climate change affects Arctic shipping and threatens sovereignty (*see* Section 9.2)

Shrinking sea ice resulting from climate change allows for increased marine traffic in the Arctic Ocean, including through the Northwest Passage (NWP). Climate change and its impacts underscore the need to strengthen rules and capacities for demonstrating Canada's effective stewardship of the NWP and ensuring safe, secure and sustainable navigation as the ice melts.

Transboundary marine and freshwater agreements generally do not consider climate change (*see* Section 9.3)

Canada's transboundary marine and freshwater agreements were not created with climate change in mind. In collaboration with international partners, Canada has an opportunity to show leadership in preserving long-term cooperation and protecting shared resources by building on adaptive practices recognized as successful.

Climate change presents risks and opportunities for international trade (*see* Section 9.4)

Canada is dependent on international trade and will increasingly experience economic effects from extreme weather and climate change impacts and adaptation elsewhere in the world, especially when occurring in countries with which Canada has strong trade ties.

Climate-related human migration and displacement will increase demands for immigration to Canada (*see* Section 9.5)

Tropical cyclones, floods, droughts, wildfires and food insecurity displace millions of people each year. Climate change will generate growing numbers of migrants by mid- to late century, especially in Least Developed Countries in sub-Saharan Africa, Asia, and Latin America and the Caribbean. Canada will come under growing internal and external pressure to accept larger numbers of migrants from climate-disrupted regions.

Increased demand for international assistance is expected (*see* Section 9.6)

Climate change can undermine human security in developing countries and increase demands for Canadian international assistance. Canada is addressing climate risk to development and humanitarian goals by providing financial and technical assistance for adaptation and climate resilience.

9.1 Introduction

This chapter assesses the risks and opportunities facing Canada from indirect impacts of climate change and discusses action taken to assess and manage them. It focuses on Arctic shipping and sovereignty over the Northwest Passage, transboundary resource management, international trade, climate-related human migration and displacement, as well as Canada's role in supporting climate risk reduction and adaptation through international assistance. The impacts of climate change and variability do not stop at national borders; they interact with social processes, structures and institutions that can amplify, spread or dampen risk (Moser and Hart, 2015). These pathways of impact include biophysical flows (e.g., freshwater resource sharing), trade and flows of finance and people (Stockholm Environment Institute, 2013). Actions taken to adapt to climate change can also have ramifications beyond the areas targeted for implementation (Stockholm Environment Institute, 2018). Therefore, it is important to explore vulnerabilities and impacts originating outside of Canada's borders, as well as international dimensions of trends and events occurring in Canada, even though they are rarely accounted for in climate change assessments and adaptation planning (Challinor et al., 2017; Moser and Hart, 2015).

The scope of international dimensions of climate change and adaptation is vast, including transboundary, teleconnected and cascading effects (Benzie and Persson, 2019). Transboundary effects spread between neighbouring countries. Teleconnected effects spread through linkages over large distances. Cascading effects result from an initial hazard that generates a sequence of interacting impacts and responses. Figure 9.1 illustrates some of the indirect climate change impacts for Canada and related policy responses. Despite a growing awareness of the risks to a country from the observed and projected impacts of climate change globally, particularly in relation to national security (Canadian Forces College, 2018), the potential consequences for Canada remain poorly understood.

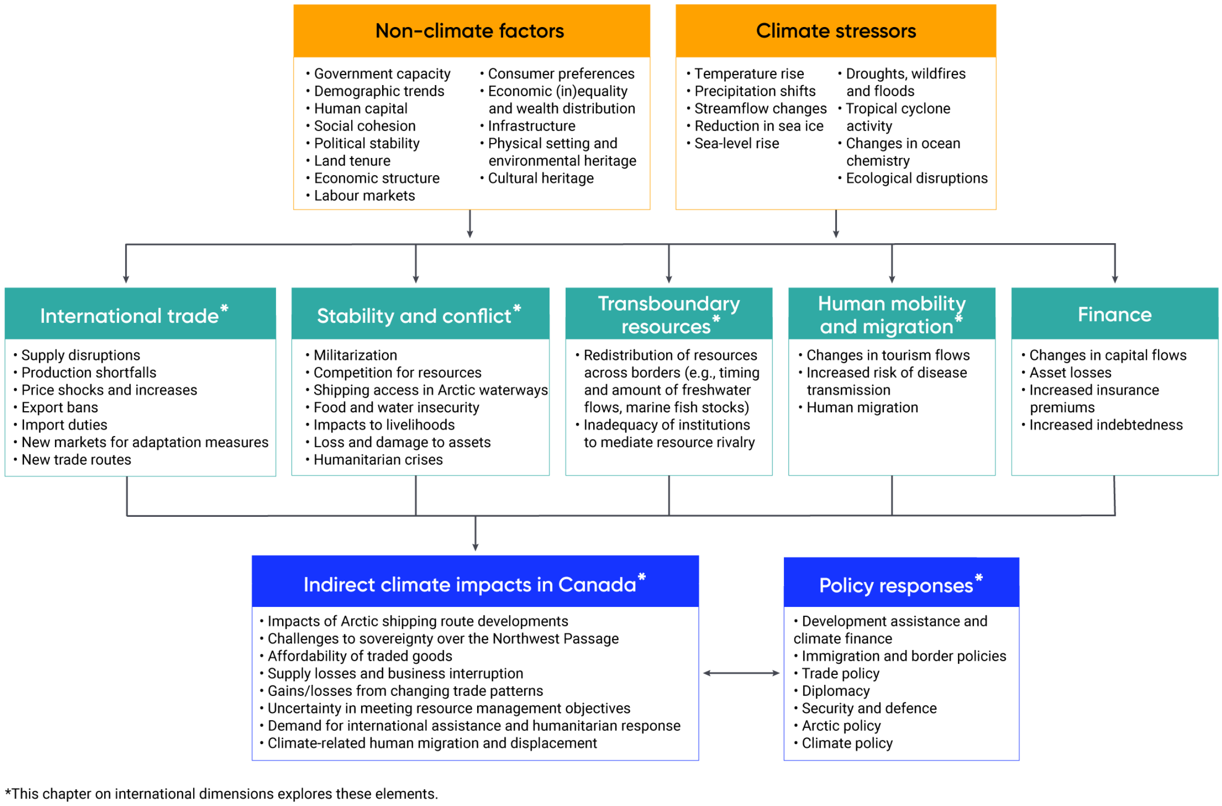


Figure 9.1: Examples of Canada's exposure to indirect impacts of climate change with international dimensions. Source: Adapted from Hildén et al., 2020.

This chapter draws from several sources of published literature to explore select indirect climate impacts for Canada, representing a mix of transmission mechanisms, scales of impact and opportunities for adaptation. The chapter starts by describing the risks to Canada from increased foreign shipping and transportation in Canada's Arctic waterways, focusing on the Northwest Passage and Canada's sovereign claims thereto. It then examines the capacity of transboundary marine and freshwater agreements to adapt to the increased uncertainties posed by rapidly changing climate and hydrologic and ocean conditions, contrasting agreements in place between countries or governing marine basins with adaptive best practices. For both Arctic shipping and sovereignty and transboundary resource management, climate change adaptation includes actions to promote environmental stewardship, preserve long-term cooperation and recognize the unique roles of Indigenous people. The chapter then explores economic risks and opportunities for Canada from climate-related disruptions to supply chains and distribution networks and from shifting patterns of global trade in response to climate impacts. Adaptation in this context not only focuses on protecting Canada's economic interests, but also acknowledges the negative effects of long-term adjustments in trade for communities beyond Canada's borders. The final two sections relate to Canada's capacity and will to engage on the global stage in stemming instability and conflict in climate-vulnerable regions of the world. After describing the links between climate and human migration, as well as climate and human security, the chapter assesses the implications of climate change on demands for immigration, refugee resettlement and international assistance programming in Canada.

The chapter concludes by identifying knowledge gaps and emerging issues that cut across impact areas. Further attention on adaptation governance in the context of cross-border risks, as well as Canada's role in strengthening the climate resilience of global food systems are two emerging issues. The need for increased use of assessment tools that address the methodological challenges of bounding complex problems, as well as improved capacity in economic modelling are also highlighted. Overall, it is evident that Canada has an opportunity to show leadership in developing knowledge and tools to prepare for multi-faceted, multi-scale climate risks and in strengthening international cooperation to support global stability and the well-being of communities in a climate-disrupted world.

9.1.1 Overview of findings from past assessments

Past assessments have covered international dimensions of climate change impacts and adaptation for Canada. *From Impacts to Adaptation: Canada in a Changing Climate* (Lemmen et al., 2008) included a chapter on Canada in an international context. This assessment concluded that climate change impacts elsewhere in the world and adaptation measures to address them could affect Canadians, the competitiveness of some Canadian industries, as well as international assistance, peacekeeping and immigration. It also found that Canada has the capacity and obligation under the UN Framework Convention on Climate Change to assist developing countries to adapt to climate change. The chapter emphasized that little research had been undertaken to understand the policy and business implications of these impacts from a Canadian perspective.

Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation (Warren and Lemmen, 2014) included two chapters of relevance. The Adaptation chapter included a section on the international status of adaptation to provide a context by which to measure Canada's own progress. Coverage focused on the status of adaptation in Organisation for Economic Co-operation and Development (OECD) countries. It concluded that adaptation implementation was in the early stages in most, if not all, developed countries, with rare instances of legislated mandates for adaptation. It also concluded that national adaptation strategies, although useful for signalling political commitment, did not always lead to action (Eyzaguirre and Warren, 2014). The Industry chapter assessed research on climate change adaptation and international trade (Kovacs and Thistlethwaite, 2014). It concluded that the topic remained an emerging field, highlighting evidence of exposure to climate change risk through disruptions to supply chains and distribution networks affecting Canadian trade markets and of opportunities to export financial risk-transfer tools to vulnerable regions. Canadian research was unavailable or not referenced.

9.2 Climate change affects Arctic shipping and threatens sovereignty

Shrinking sea ice resulting from climate change allows for increased marine traffic in the Arctic Ocean, including through the Northwest Passage (NWP). Climate change and its impacts underscore the need to strengthen rules and capacities for demonstrating Canada's effective stewardship of the NWP and ensuring safe, secure and sustainable navigation as the ice melts.

Over the past decades, the extent and thickness of summer sea ice in Canada's Arctic marine areas have steadily decreased. Physical access to Arctic resources and waters allows for increased economic activity and sea traffic, including through the Northwest Passage (NWP). The NWP links the Atlantic Ocean (Baffin Bay) and Pacific Ocean (Beaufort Sea). The shipping distance between New York and Shanghai through the NWP is about 20% shorter than that through the Panama Canal. On grounds of environmental protection, the United Nations Convention on the Law of the Sea confers coastal Arctic countries like Canada the right to regulate vessel traffic in ice-covered waters, even in straits where foreign vessels could otherwise enjoy the right to unimpeded transit passage. Although summer sea ice might not disappear entirely for another 30 years, increased warming under climate change and reductions in sea ice could pose challenges for Canada's legal arguments to regulate shipping across the channels and straits of the NWP. Sustained foreign use of these Arctic shipping lanes could render the NWP an international strait. Gradual physical access to maritime areas adds to the importance of bolstering Canada's ability to proactively exercise stewardship of the NWP to achieve a combination of diplomatic, informational, military and socioeconomic objectives, with the protection of the rights of Indigenous people cutting across them all.

9.2.1 Introduction

Canadian and international interest in the future of Arctic navigation increased in the mid-2000s, driven by warming temperatures, the rapid retreat of sea ice and a commodity boom that raised expectations about the profitability of developing northern energy and mineral resources (Exner-Pirot, 2016; Guy and Lasserre, 2016; Harber, 2015; Farré et al., 2014). This section provides information on sea-ice reduction and navigation in the Canadian Arctic, then focuses on climate-related risks to Canada's sovereignty over the Northwest Passage (NWP) and discusses the country's capacity for effective stewardship of the NWP through safe, secure and sustainable shipping as climate change intensifies.

9.2.2 Climate, sea ice and Arctic navigation

With the rapid retreat of sea ice in the Arctic Ocean (Derksen et al., 2019) and increased physical access to the region and its resources, the Arctic is now on the world stage. The rapid changes underway in the Arctic marine environment, including the declining extent, duration and thickness of sea ice and changes in the distribution and abundance of fish and other biological resources, fuel competing narratives for the future of the region. Economic narratives centre on the exploitation of, and competition over, natural resources (oil, gas and mineral resources, fish stocks), growth of the Arctic tourism industry and improved marine transportation (Ash, 2016; Arruda, 2015; Bader et al., 2014; Williams et al., 2011). Military security narratives focus on strengthened defence capabilities by northern circumpolar countries (e.g., Åtland, 2014) and potential threats from criminal elements (terrorists, smugglers, poachers) (Arctic Domain Awareness Center, 2017; Charron, 2015; Flake, 2014). Environmental narratives portray the Arctic as a maritime global commons with climate change implications for the entire planet (Bennett, 2015), and as a fragile and pristine area potentially threatened by resource or shipping disasters (Dodds and Hemmings, 2015). Finally, cultural and rights-based narratives portray Arctic lands, sea and ice as a homeland for Inuit peoples whose historic use and occupation have bolstered countries' credibility to sovereignty claims (Inuit Tapiriit Kanatami, 2017; Dodds and Hemmings, 2015; Arnold, 2012; Inuit Circumpolar Council, 2009). Common across all frames are global drivers of change in the region and the ripple effects of these drivers (*see* Figure 9.2). Climate change impacts, their links to new shipping lanes, and related disputes over Arctic waterways and territories are one slice of this complex cause-effect pathway.

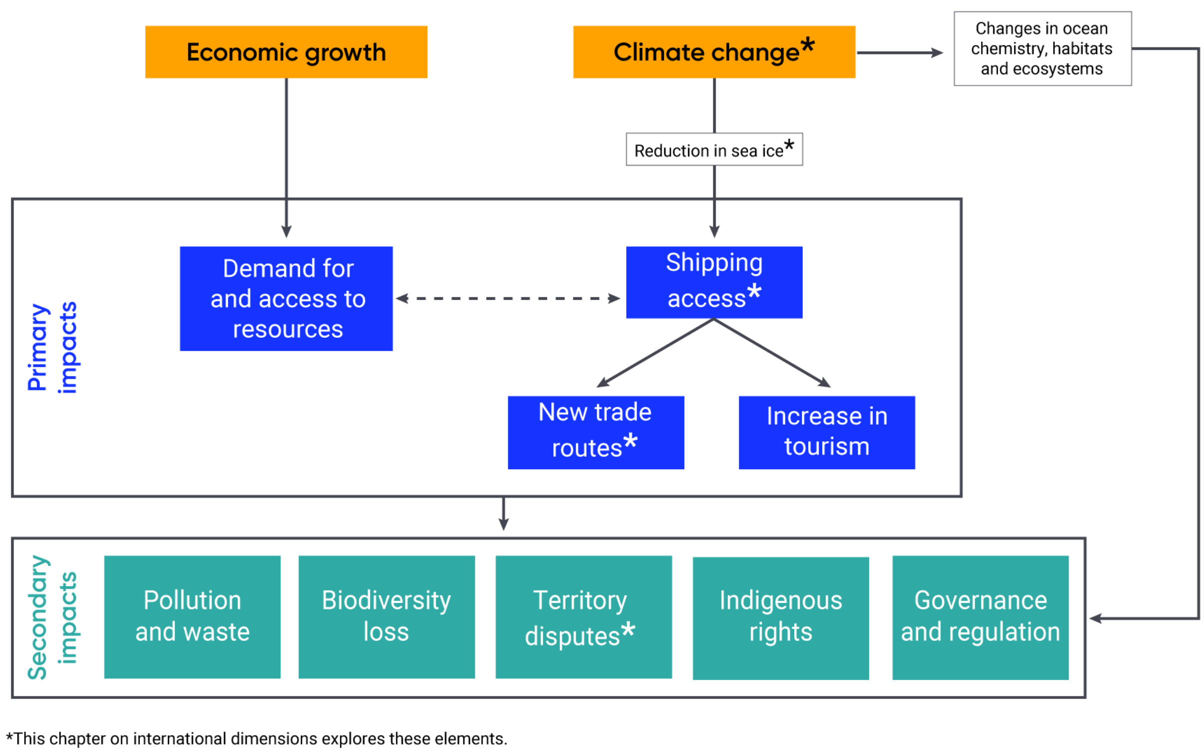


Figure 9.2: Global drivers of Arctic marine change. Source: Adapted from Williams et al., 2011.

Sea ice patterns shape navigability in Arctic waters, as do strong and variable winds, wave conditions and storminess (Ng et al., 2018; Pendakur, 2017). Since the late 1960s, rising air temperatures have contributed to declines in the extent, thickness and age of summer sea ice in the Arctic Ocean. The extent of sea ice in the summer has decreased by 5% to 20% per decade in the Canadian Arctic, including areas that span the NWP (*see* Box 9.1; Derksen et al., 2019). Ice in the Canadian Arctic that used to accumulate over multiple years without melting is giving way to thinner, seasonal ice, with the greatest drop in multi-year ice seen in the Beaufort Sea and the Canadian Arctic Archipelago (Derksen et al., 2019). Under a range of future climate scenarios, scientists project continued reductions in seasonal sea ice, with the gradual opening of major waterways to ice-free conditions for part of the year (Derksen et al., 2019; Meredith et al., 2019; Ng et al., 2018). Increasing wave energy and heat released from wave mixing in the upper ocean can further accelerate sea ice reductions (Greenan et al., 2019). Predictions on the timing of ice-free conditions differ based on the definitions of "ice-free" and global greenhouse gas (GHG) concentration scenarios used. Relative to other sea routes in the Arctic Ocean, the Canadian Arctic Archipelago is likely to see continued sea ice further into the future, which will be transported southward into the NWP and pose an ongoing ice hazard for shipping (Derksen et al., 2019; Ng et al., 2018; Greenert, 2014). Analysis of wind, wave and storm conditions in the Arctic is limited by gaps in monitoring data and complex ice–ocean–atmosphere interactions (Ng et al., 2018). Studies indicate opposing trends for wind speed, but wave heights and wave-season duration in the Canadian Arctic are projected to increase over this century as sea ice declines (Greenan et al., 2019; Ng et al., 2018). Observations on sea ice changes by Inuit elders and experienced hunters in communities along the Canadian Arctic Archipelago support these scientific findings (Panikkar et al., 2018).

Box 9.1: Arctic sea routes are waterways to navigate through the Arctic Ocean

Three routes connect the Pacific and Atlantic Oceans: the Northwest Passage (NWP), the Northeast Passage (NEP) and the Transpolar Sea Route (TPR) (*see* Figure 9.3; Østreng et al., 2013). The NWP encompasses the straits and sounds of the Canadian Arctic Archipelago and follows along the northern slope of Alaska; it has five recognized passages (Arctic Council, 2009). The NEP follows the Russian and Norwegian coastlines. The TPR crosses the Arctic at the North Pole. Two additional waterways are the Northern Sea Route, which is the part of the NEP between the Bering Strait and the Kara Sea, and the Arctic Bridge that connects Russia to Canada through Hudson Bay.

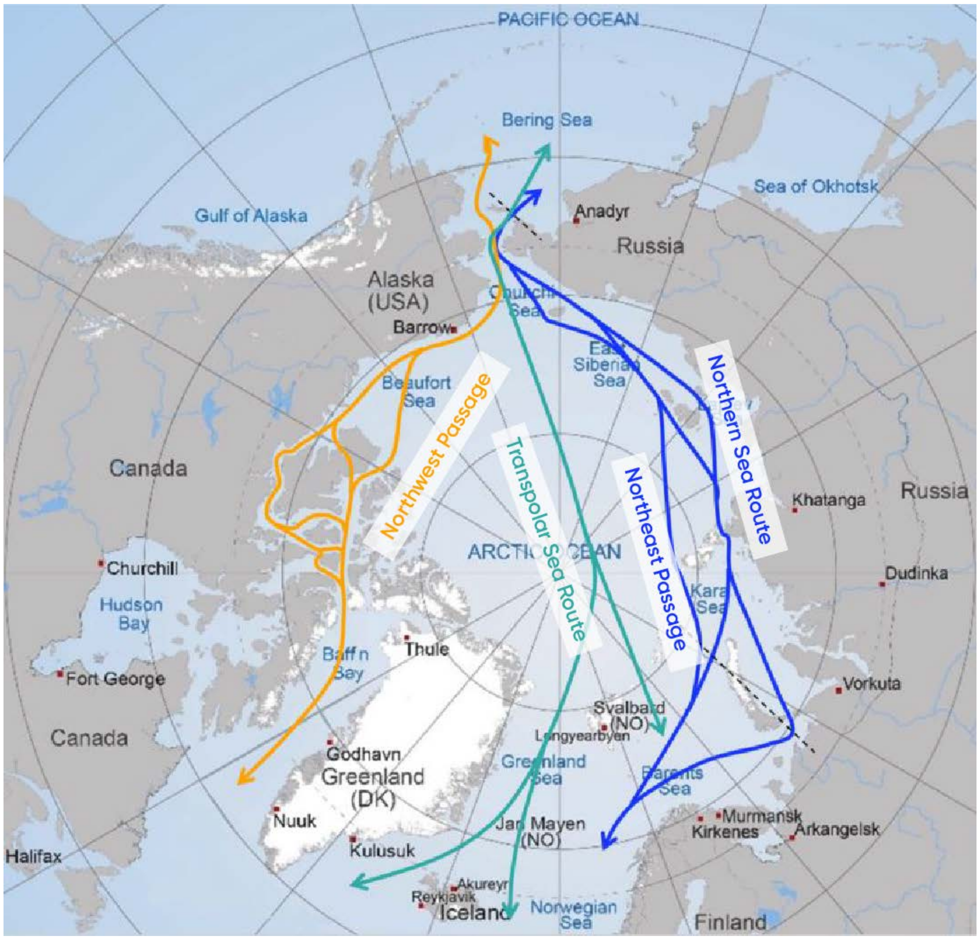


Figure 9.3: Map of Arctic sea routes. Source: Dyrcz, 2017.

Arctic navigation is attractive because of the potential to reduce shipping distances and costs, and save fuel and time, compared to southern sea routes (*see* Table 9.1).

Table 9.1: Distances (in kilometres) between major ports using two Arctic sea routes compared to standard routes

ORIGIN-DESTINATION	PANAMA CANAL	SUEZ AND MALACCA	NORTHWEST PASSAGE	NORTHEAST PASSAGE
London–Yokoyama	23,300	21,200	14,080	13,841
Rotterdam–Shanghai	25,588	19,550	16,100	15,793

ORIGIN-DESTINATION	PANAMA CANAL	SUEZ AND MALACCA	NORTHWEST PASSAGE	NORTHEAST PASSAGE
Hamburg–Seattle	17,110	29,780	13,410	12,770
Rotterdam–Vancouver	16,350	28,400	14,330	13,220
Rotterdam–Los Angeles	14,490	29,750	15,120	15,552
New York–Shanghai	20,880	22,930	17,030	19,893
New York–Hong Kong	21,260	21,570	18,140	20,985
New York–Singapore	23,580	19,320	19,540	23,121

Note: The Northwest Passage route uses the McClure Strait. Grey = shortest distance, blue = within 15%.

Source: Guy and Lasserre, 2016.

Vessel activity is increasing in Arctic waters and climate change and sea ice reductions are among the factors that have contributed to this rise (Guy and Lasserre, 2016; Pizzolato et al., 2016). The types of vessels operating in the region include bulk carriers and container ships for transit to southern markets; cruise ships, pleasure crafts, tankers, general cargo, and tug and barge as destination and resupply traffic; as well as government vessels and icebreakers (Dawson et al., 2018; Beveridge et al., 2016; Guy and Lasserre, 2016; Lasserre, 2016). Vessel traffic through Canadian Arctic waterways almost tripled between 1990 and 2015 (IPCC, 2019; Hildebrand et al., 2018, Guy and Lasserre, 2016; PEW Charitable Trusts, 2016; Charron, 2015). Distances travelled per vessel type have also increased (Dawson et al., 2018). Pizzolato et al. (2016) coupled spatial datasets on shipping activity and sea ice concentrations in the Canadian Arctic from 1990 to 2015, revealing a statistically significant correlation between these two variables in Beaufort Sea, Western Parry Channel, Western Baffin Bay and Foxe Basin. In other regions of the Canadian Arctic, sea ice conditions were not a predictor of trends in shipping activity (Pizzolato et al., 2016), with non-climatic factors—such as the ability to maintain predictable schedules—clearly influencing ship operators' decisions (Beveridge et al., 2016; Lasserre et al., 2016). At present, transit traffic in the NWP remains too low to attract significant commercial or military attention (Charron, 2015; Lackenbauer and Lajeunesse, 2014). Between 2000 and 2014 complete transits through the NWP ranged from six to 30 per year, with pleasure crafts accounting for the fastest growing transits (Beveridge et al., 2016; Guy and Lasserre, 2016; Government of Northwest Territories, 2015).

Although vessel traffic will almost certainly increase, affordable and safe Arctic shipping will be slow to develop, with the NWP unlikely to become the optimal route for international shipping (Lackenbauer and Lajeunesse, 2014). Medium-term projections (2030s to 2050s) indicate annual numbers of vessel traffic through Arctic sea routes in the hundreds (e.g., Greenert, 2014); over 5% growth in annual shipping activity (Williams et al., 2011); expanded navigability for open water and moderately ice-strengthened vessels in September (Smith and Stephenson, 2013); and shifts in trade flows (Bekkers et al., 2018). However, the potential of Arctic routes as substitutes for conventional southern trade routes is likely overstated (Guy and Lasserre, 2016; Farré et al., 2014). Opportunities for expansion in Arctic shipping are tempered by continuing challenges to navigation and safety posed by mobile summer sea ice, drifting ice that clogs straits and channels, older, thicker ice and other climate elements (Dirksen et al., 2019; Ng et al., 2018; Pendakur, 2017; Farré et al., 2014). Uncertainties in global markets, commodity prices and technological innovation, among other non-climate factors, also limit shipping potential (Johnston et al., 2017; Andrew, 2014). These challenges translate into risks and costs to operators: more expensive ship construction related to ice strengthening; seasonal scheduling challenges; the need for equipment to spot and cope with ice and crews with unique experience; and high insurance premiums (Beveridge et al., 2016; Guy and Lasserre, 2016). The economic viability of Arctic shipping, compared with southern routes, is also hampered by technological and infrastructure deficiencies, including a lack of modern deep-water ports and other services offered to transiting ships, limited search and rescue capabilities, poor charting and mapping of Arctic waters, and continued difficulties with seasonal-ice predictions (Melia et al., 2017; Guy and Lasserre, 2016). Within the global Arctic, Canada and Russia have adopted different patterns in developing shipping lanes (*see* Table 9.2; Guy and Lasserre, 2016). As a result, international shipping through the NWP, with underdeveloped infrastructure and services, may be less preferable than shipping through the Northern Sea Route (Beveridge et al., 2016; Bonds, 2016; Bennett, 2014; Farré et al., 2014). For example, according to survey research, European shipping companies strongly view icebreaker escort and navigational aids as essential Arctic navigation services (Lasserre et al., 2016), which are attributes of the Northern Sea Route.

Table 9.2: Differences in governance of the Northern Sea Route and the Northwest Passage for vessel traffic

RUSSIA AND THE NORTHERN SEA ROUTE	CANADA AND THE NORTHWEST PASSAGE
• Special administrative body created to manage traffic between the Bering Strait and Kara Gate (Northern Sea Route Administration) • Applications for transit • Mandatory transit fee in exchange for providing piloting, icebreaker escort services and the possibility of docking at small ports in the event of an emergency • Mandatory pilotage • Encourage ships to be escorted by icebreakers • At least nine deep-water ports • Network of search and rescue centres in the Arctic	• No mandatory transit fees • Mandatory registration of ships carrying over 300 tons of gross tonnage, or carrying pollutants or dangerous goods • No service provided other than navigation aids (seasonal buoys, frequent transmission of ice maps) • No deep-water ports • Search and rescue bases are located far to the south (Gander, Halifax, Trenton, Cold Lake and Comox)

Source: Guy and Lasserre, 2016

9.2.3 Climate-related risks to Canada's control over the Northwest Passage

Although a substantial rise in vessel traffic volumes and international transits through the NWP is unlikely in the short term, preparing for long-term growth in navigation and maritime trade through the NWP and related environmental, social, economic, cultural and geopolitical risks is prudent (Dawson et al., 2020a; Hauser et al., 2018; Cotter, 2017). However, the NWP has been held up as a contested resource and a source of future international tension, particularly with increased Asian interest in the Arctic and its natural resources (Levitt, 2019; Exner-Pirot, 2016; Landriault, 2016; Rothwell, 2015; Wallin and Dallaire, 2011; Huebert, 2010). Climate change impacts, including shrinking sea ice, could weaken Canada's sovereign claim to the NWP. Climate change also challenges the capacity of Canadian infrastructure and systems in place (e.g., search and rescue, offshore surveillance) to demonstrate effective stewardship of the NWP.

In legal terms, sovereignty refers to recognized rights of exclusive jurisdiction over a territory (Cox, 2015). Canada claims sovereignty over all waters of its Arctic Archipelago and regards the NWP as "internal" waters over which Canada has authority to regulate entry and control access to its various routes (*see* Video 9.1; Lalonde, 2019; Lackenbauer and Lalonde, 2017b). Historic occupation and use of Arctic lands, sea and ice by Indigenous Peoples, enclosure of the Arctic Archipelago within Canada's baseline, and enforcement of environmental regulations in the NWP as part of the 1970 Arctic Waters Pollution Prevention Act (AWPPA) are key components of Canada's sovereignty claims (Guy and Lasserre, 2016; Cox, 2015; Wright, 2014; Zellen, 2010; Carnaghan and Goody, 2006). As well, Canada has asserted military control in the North through human resource and infrastructure expenditures. This includes the expansion of the Canadian Rangers, a fleet of patrol vessels, a Canadian Forces training centre, a deep-water fuelling facility, and increased radar and satellite capacity. Maintaining the NWP as internal waters is also a priority for the Canadian Inuit, as the passage is part of their Arctic homeland, Inuit Nunangat (*see* Video 9.2; George, 2019a; Inuit Circumpolar Council, 2018). Pollution, oil spills and negative impacts on marine mammals are among the Inuit's main concerns related to increased shipping activity (Dawson et al., 2020a; Arctic Council, 2009).

Video 9.1: Sovereignty: Political science and security scholars' perspective on Arctic sovereignty and shipping in the Northwest Passage. Source: Baldassari, 2017, 2013. https://vimeo.com/104400714

Video 9.2: Nilliajut 2: Inuit perspectives on the Northwest Passage, shipping and marine use. Source: Inuit Tapiriit Kanatami, 2018. https://www.youtube.com/watch?v=0EGzKIQo0jY

Perceived threats to Canada's sovereign claim over the NWP arise from countries' differing opinions on the status of the NWP as internal Canadian waters (Lackenbauer and Lalonde, 2017b). Of the five states with Arctic coasts—Canada, Denmark, Norway, Russia and the United States—the United States has long viewed the NWP as an international strait where foreign ships and aircraft can freely transit the waters and airspace (Lalonde, 2019; U.S. Government, 2013). Non-Arctic nations have weighed in on the NWP controversy. Of note, Germany, a country with observer status at the Arctic Council, has campaigned for freedom of navigation in the Arctic Ocean (including the NWP) (Federal Foreign Office of Germany, 2013). In its 2018 Arctic Policy, China, another Arctic Council observer, invoked the importance of freedom of navigation and the right to use Arctic shipping routes (People's Republic of China, 2018). Despite alarmist concerns (Exner-Pirot, 2016), Canada's claims to the NWP have been largely unchallenged. To date, all maritime disagreements have been well managed by established international mechanisms, providing a foundation for future cooperation among Arctic states and beyond. Canada's claims and regulations in the Arctic are typically complied with, and there are no current threats to sovereignty (Charron and Fergusson, 2018).

Competing views exist on whether climate change weakens Canada's position on claims to the NWP (Burke, 2017; Rothwell, 2015). Critical uncertainties relate to the extent of international traffic in the NWP and the interpretation of Article 234 of the United Nations Convention of the Law of the Sea (UNCLOS), which grants coastal states the right to enact laws and regulations to control marine pollution from vessels in "ice-covered" waters within its Exclusive Economic Zone (UN Convention on the Law of the Sea, 1982). For the NWP to be considered an international strait, it would have to meet geographic and functional requirements: it must connect two bodies of the high seas (as it does) and must be considered “useful” as determined by a sufficient number of transits (Carnaghan and Goody, 2006). Legal precedents suggest that the small number of current transits and those expected in the medium term would not qualify the NWP as a useful route for international maritime traffic. However, if accelerated sea ice melting enabled a substantial rise in commercial shipping, perceptions of the NWP as an international strait would intensify (Lackenbauer and Lalonde, 2017a; Cox, 2015; Huebert, 2001). The power conferred by UNCLOS Article 234 to regulate shipping in the interest of environmental protection of ice-covered areas has served to expand Canada’s jurisdiction in Arctic waters (Burke, 2017; Farré et al., 2014). As sea ice retreats and navigation becomes less hazardous, Canada’s ability to count on Article 234 for international legitimacy could diminish (Rothwell, 2015; Farré et al., 2014). Russia, which also invokes Article 234 to regulate shipping activity in its Exclusive Economic Zone along the Northern Sea Route, could also face challenges to its claims as sea ice cover diminishes (Flake, 2014).

Regardless of legal stances over sovereignty in the NWP and the right to control activities of other nations, Canada can proactively exercise stewardship of the NWP (Cox, 2015) by focusing on safe, secure and sustainable development of shipping routes (Dawson et al., 2020a; Lackenbauer and Lajeunesse, 2014). At present, Canada is poorly equipped to enforce environmental protections in Canada’s Arctic waterways (Giguère et al., 2017; Cox, 2015; McRae, 2007; Huebert, 2003). Canada remains deficient in infrastructure (e.g., charting; navigational, weather and communication support services; ports, harbours and terminals; ship repair and waste management for vessels) and emergency response capabilities, including for oil spills. Adequate infrastructure and the ability to respond to emergencies are critical for protecting the fragile Arctic environment (Hildebrand et al., 2018; Lajeunesse, 2018; Giguère et al., 2017; Arctic Council, 2009). Maintaining maritime domain awareness, and monitoring and serving such an expansive, remote and rugged region, will remain financially and logistically challenging (Guy and Lasserre, 2016; Dawson et al., 2014). Aside from pursuing coordination with Arctic littoral states, a practical focus on the needs of international operators serving resupply and destination traffic is one way to manage risk posed by international ships (Lackenbauer and Lajeunesse, 2014; Charron, 2005). This strategy also commands respect for Canadian sovereignty over the NWP, just as Russia’s approach to providing pilotage and icebreaking services and mandating their use, as well as its investments in maritime infrastructure and search and rescue capabilities, support its claim to Northern Sea Route waters (Cotter, 2017).

9.2.4 Strategies to adapt to increased shipping activity in the Northwest Passage

Managing indirect impacts of climate change, such as increased international vessel traffic in the NWP, competition over new shipping lanes and affronts to Canada’s sovereignty, is less about reducing specific climate threats and more about enhancing capabilities to meet valued outcomes even as the climate changes (Meredith et al., 2019; Stockholm Environmental Institute, 2013). Public opinion in Canada on how to assert Arctic sovereignty has shifted over the years, from a marked preference for military capabilities and surveillance in 2000–2005 to a mix that also includes diplomacy, attention to the needs of northern and Indigenous communities, science and environmental protection in 2011–2014 (Landriault, 2016). The following discussion on capabilities to build Canada’s capacity to develop safe, secure and sustainably managed Arctic waterways in a rapidly changing environment draws on three frameworks: the Arctic

Resilience Action Framework (Arctic Council, 2017); a framework to foster strategic capabilities for climate security (Werrell and Femia, 2019); and the Circumpolar Inuit Declaration on Sovereignty in the Arctic (Inuit Circumpolar Council, 2009). The multi-faceted strategies to build adaptive capacity comprise diplomatic, informational, military and socioeconomic themes, and the protection of the rights of Indigenous people is an element of each.

Diplomatic capabilities include international cooperation and actively strengthening international standards governing the Arctic. Arctic governance comprises a patchwork of bilateral and multilateral agreements, stemming from the Arctic Council and International Maritime Organization, and anchored in UNCLOS (Arruda, 2015; Borgerson, 2013). Existing instruments have been effective in driving consistent and cooperative action to date (House of Commons, 2019; Plouffe, 2011; Byers, 2010; Government of Canada, 2010; Byers and Lalonde, 2009), but need to reflect changing conditions—climatic and otherwise (Byers, 2010). For example, the mandatory International Code for Ships Operating in Polar Waters ("Polar Code") adopted in 2017 clarifies shipping and navigation standards related to commercial vessels, operational concerns, search and rescue in polar waters, and environmental protection. Monitoring and forecasting of ice conditions will be critical to the Code's effective application (Guy and Lasserre, 2016). The rise in Arctic shipping has led to a higher rate of reported accidents per kilometre travelled compared to southern waterways (Council of Canadian Academies, 2016), noise and air pollution (Marelle et al., 2018; Halliday et al., 2017), as well as disruptions to wildlife and cultural activities of community residents (Olsen et al., 2019; Panikkar et al., 2018). These trends lend urgency to resolving practical issues among littoral states and, in partnership with Inuit, on management and funding of navigation services such as traffic control, navigation aids, environmental protection and clean-up procedures (Charron, 2005). Climate change adaptation of the rapidly evolving cruise shipping industry is one area of active research (*see* Case Story 9.1), as the cruise ship sector is in need of improved governance (Pashkevich et al., 2015).

Informational capabilities refer to collection and dissemination of information on climate change risk and responses. Climate change is one among many pressures that shape Arctic shipping and its effects on people and ecosystems. Therefore, governments and others are turning to holistic approaches that incorporate spatial, analytical and modelling methods to understand past and potential damages and opportunities brought by marine vessel activity (Pickard et al., 2019). The Arctic Corridors group, in partnership with Northern Voices, has studied and written many reports about climate change and the cumulative effects of marine shipping (Carter et al., 2019). A number of data resources and tools exist to facilitate the integration of direct climate change impacts (e.g., changing sea-ice patterns, precipitation events, strong and variable winds, changing sea levels and wave patterns, permafrost degradation and enhanced coastal erosion) into plans and decisions related to marine navigation and to assess the strength of management strategies (Debortoli et al., 2019; Pendakur, 2017). For example, efforts to determine safe navigation routes are building on data collected to measure the depths of Arctic water as part of Canada's submission to UNCLOS on its extended continental shelf (Global Affairs Canada, 2019b). Consistent with its mandate to maintain coastal infrastructure and safe secure waterways, the Department of Fisheries and Oceans developed a web-based planning tool to generate estimates of climate variability and change in the Beaufort Sea, Davis Strait and the Mackenzie Delta region (Department of Fisheries and Oceans, 2018). However, trends and projections of socioeconomic variables, including the indirect impacts of climate change, are less widely studied. Understanding and evaluating future climate-related risks of international vessel traffic in the NWP can be challenging because of the uncertainties involved. Foresight tools, such as scenario building and horizon scanning, can help identify management actions that are robust to a range of futures (Fetzek et al., 2017). Used in national security planning (e.g., Pezard et al., 2018) foresight tools also aid in climate change adaptation planning and in strengthening emergency response. Of equal importance to the creation of climate risk information are institutions charged with translating insights for decision makers to take action (Arctic Council, 2017; Fetzek et al., 2017).

Military capabilities correspond to those possessed by the armed forces and national defence agencies. As a member of the North Atlantic Treaty Organization (NATO), which has recognized climate change as a threat multiplier, Canada is aware of the potential security threats of climate change. Canada's Strong, Secure, Engaged defence policy commits to increasing enforcement capacity, situational awareness and monitoring of Arctic waters, referring to climate change as one of the drivers behind the need for these enhanced capabilities (Government of Canada, 2017b). A companion Defence Energy and Environment Strategy guides "greening" efforts by Canadian defence (Minister of National Defence, 2017). Both the defence policy and greening strategy outline investments and concrete actions to reduce the carbon footprint of defence installations and operations, but are far less specific on investments and actions required to adapt to climate change. Canada's military is already stretched to respond to climate-related emergencies at home and overseas, with climate change expected to increase the demand for military assistance (Major and Shivji, 2019). The integrity of military assets and facilities could be at risk from climate change. While the United States has identified its military assets and operations most vulnerable to climate change, as a basis for setting priorities (Center for Climate and Security, 2020), Canada has not. Symposia on climate change and security, such as those held by the Canadian Forces College in 2018 and 2020 (Canadian Forces College, 2021), can help raise the profile of these gaps to senior decision makers.

Capabilities in the realm of socioeconomic development centre on capital and infrastructure investments and public policies and regulations applicable to Arctic waters that incorporate climate risk. Climate change adaptation solutions for vessels and navigation in the Arctic and for maritime infrastructure are increasingly documented and include winter-operation risk assessments, ship-specific winterization (including for mixed-ice environments), and relocation of shore-based resupply infrastructure (Meredith et al., 2019; Pendakur, 2017). They apply to both private- and public-sector operators. At a strategic and policy level, the Arctic Northern Policy Framework, the Oceans Protection Plan's Cumulative Effects of Marine Shipping initiative, the Northern Marine Transportation Corridors (now known as "Low Impact Corridors") and Strategic Environmental Impact Assessments linked to Arctic resource development (e.g., Nunavut Impact Review Board, 2019) are initiatives that could support the safe and sustainable development of shipping in the NWP (Porta et al., 2017; PEW Charitable Trusts, 2016). The Low Impact Corridors initiative in particular is a promising response to increased Arctic shipping activity (Dawson et al., 2020a), as it proposes to install the necessary services (e.g., emergency response, navigational support) and infrastructure to ensure safer navigation while considering ecological and cultural significance (Levitt, 2019). Inuit communities acknowledge the potential benefits of shipping, but urge inclusive and collaborative research to determine corridor routes with minimal negative impacts on traditional activities and sensitive ecosystems (Dawson et al., 2020a).

Case Story 9.1: Adaptation strategies for cruise ship tourism in the Canadian Arctic

Cruise ship tourism in Canada's Arctic is increasing, with activity more than doubling between 2005 and 2013 (Dawson et al., 2016). Increased physical access, the Arctic's rich cultural and natural heritage, and an expanding range of products make the Northwest Passage a popular area to visit for "frontier tourism" enthusiasts and a growing base of baby boomers with disposable income. At present, management of expedition cruise shipping takes place within the complex, multi-jurisdictional regulatory framework applicable to all shipping in the region (Dawson et al., 2014). However, cruise shipping differs from industrial shipping in a number of ways, including deviating from main shipping corridors in pursuit of ice, wildlife and culture. This involves navigating in sometimes challenging, uncharted waters, seeking access to shore locations and interacting with local residents. Researchers, private operators and Canadian Inuit organizations see the need to improve governance of the sector. Limiting the size of cruise ships entering Arctic waterways, banning the use of heavy oil in Arctic waters, establishing site guidelines for highly visited areas, and regulating cruise ship disturbances to wildlife (birds and mammals) and their habitats are examples of potential measures (Inuit Tapiriit Kanatami, 2017; Kujawinski, 2017; The Maritime Executive, 2016; Dawson et al., 2014).

Successfully managing climate change-related risks is also critical to the sustainable growth and evolution of the Arctic cruise ship industry. Qualitative research led by Dawson et al. (2016) and involving over 300 local residents, cruise operators and regional decision makers identified the seven most feasible and desirable adaptation strategies for cruise ship tourism in the Canadian Arctic (*see* Figure 9.4). Bottom-up approaches to identifying adaptation needs and priorities in climate change management tend to address current vulnerabilities and risks. If genuinely participatory, they also generate results that are consistent with local priorities, goals, norms and institutions—a foundation for implementation success.

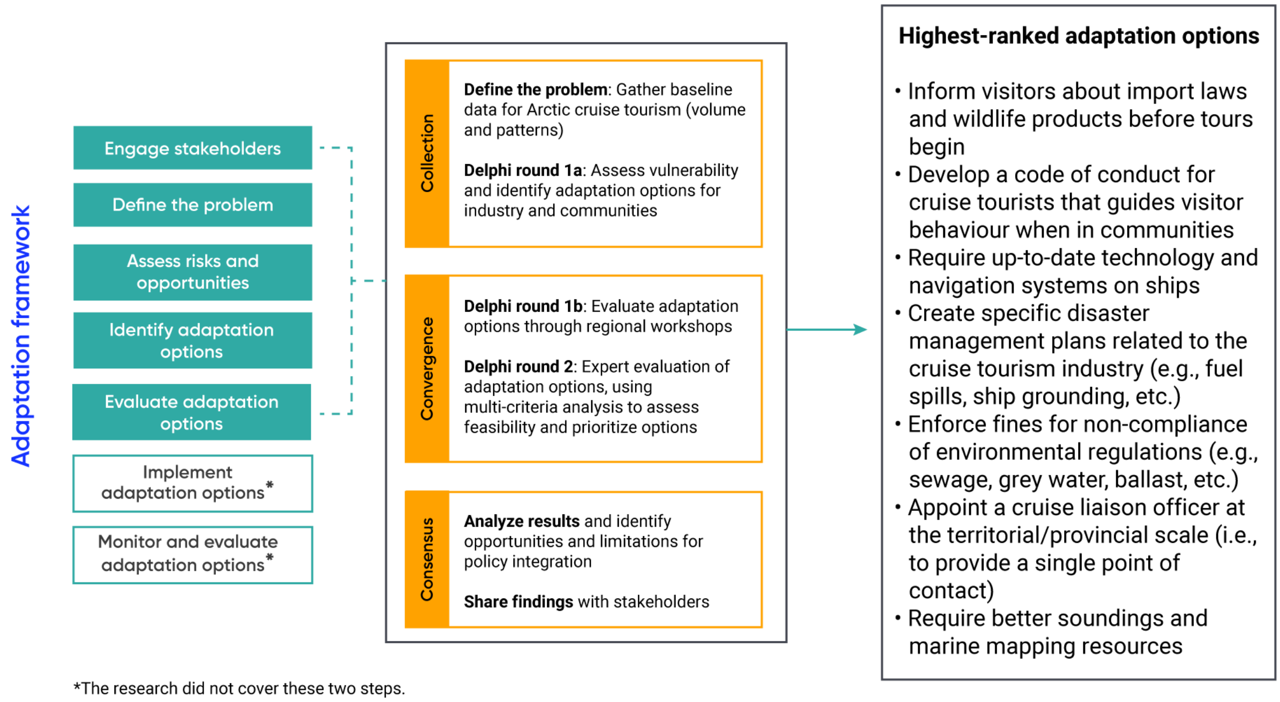


Figure 9.4: Summary of the research process used by Dawson et al. (2016) to identify promising adaptation options for cruise ship tourism in the Canadian Arctic. The Delphi technique uses iterative and structured expert elicitation to generate consensus judgments. Source: Adapted from Dawson et al., 2016.

9.3 Transboundary marine and freshwater agreements generally do not consider climate change

Canada's transboundary marine and freshwater agreements were not created with climate change in mind. In collaboration with international partners, Canada has an opportunity to show leadership in preserving long-term cooperation and protecting shared resources by building on adaptive practices recognized as successful.

Despite differences in agreements governing sharing of marine and freshwater resources across international borders, one commonality is the general assumption that environmental conditions would remain static over time. In a changing climate, relying on this assumption risks unsustainable resource use that may destabilize existing cooperative relationships. As a significant contributor to international environmental negotiations, Canada is well positioned to help modernize transboundary resource management institutions to provide more resilient frameworks for coping with uncertainty, promoting environmental stewardship and improving representation of affected groups and Indigenous governments.

9.3.1 Introduction

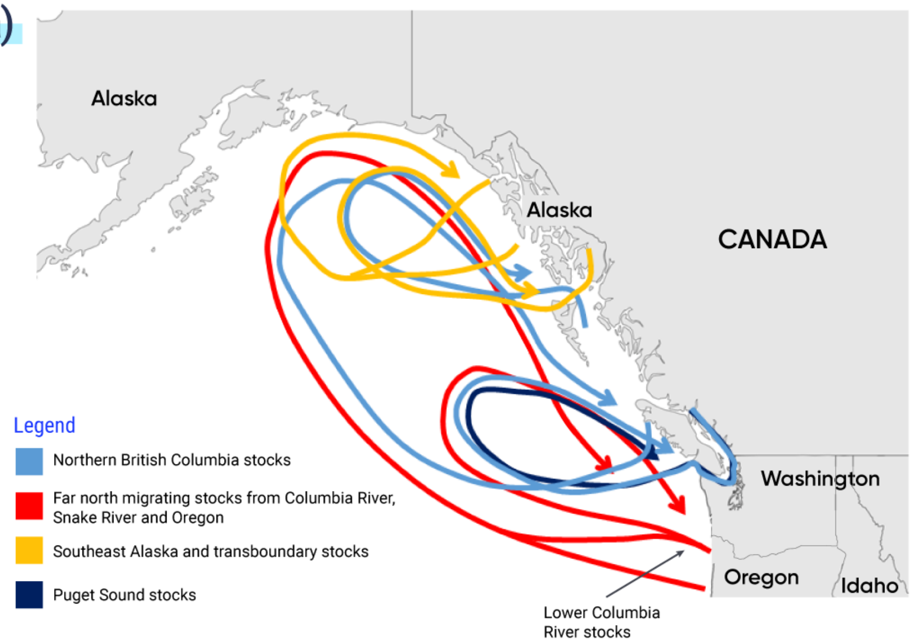
Most of the agreements governing shared marine and fresh waters that cross the Canada–U.S. border were negotiated and signed before climate change was a recognized concern. These arrangements face new challenges since they assume "stationarity." Climate change invalidates the assumption that environmental conditions can be adequately predicted based on historical information; therefore, continued reliance on stationarity threatens sustainable resource use and the stability of cooperative relationships (Sumaila et al., 2020; Britten et al., 2017; Szuwalski and Hollowed, 2016; Criddle, 2012; Craig, 2010; Hanna, 2008; Milly et al., 2008). Physical impacts like changes in the timing and volume of flows or in the frequency and duration of floods and droughts will have different economic implications across the border and will likely challenge existing allocation mechanisms. Further, because climate-related risks differ in Canada and the United States, each country will discount future benefits from shared marine and freshwater ecosystems differently, thereby complicating the ability to agree on the value of those benefits (Sumaila et al., 2011; Sumaila, 2005).

Canada's marine and freshwater systems have different characteristics yet are highly interconnected and share climate-related risks. Compared to river basins, marine systems are harder to divide into discrete ecological units and associated agreements tend to focus on a single issue (e.g., navigation, pollution, invasive species, fisheries and environmental protection). Examples include the Pacific Salmon Treaty, the Antarctic Treaty's Environmental Protocol and the Canada–U.S. Marine Pollution Contingency Plan. Freshwater agreements often consider a bundle of shared benefits together, such as hydropower production, flood management, agricultural irrigation, navigation, fisheries and water quality management. Examples include the Columbia River Treaty, Great Lakes Water Quality Agreement and the Boundary Waters Treaty. Despite these differences, there are critical connections between marine and freshwater systems. Both are subject to long- and short-term climate variation (e.g., Pacific Decadal Oscillation, El Niño Southern Oscillation) and are sensitive to shifts in water temperatures (Di Lorenzo and Mantua, 2016; Pinsky et al., 2013; Cheung et al., 2009; Hollowed et al., 2001; Mantua et al., 1997; Wood and McDonald, 1997). Anadromous species like salmon that rear in freshwater, migrate to sea, then return to their natal streams to spawn, reinforce the need to consider cumulative effects across marine, riverine, and land-based ecosystems. Agreements that acknowledge these linkages are better positioned to cope with uncertain climate futures (*see* Case Story 9.2).

Case Story 9.2: The Canada–U.S. Pacific Salmon Treaty

The Pacific Salmon Treaty (PST) (Pacific Salmon Commission, 2016a) was ratified in 1985 to prevent overfishing and improve the management of five salmon stocks shared between Canada and the United States (Miller, 1996; Yanagida, 1987). The PST was successfully renegotiated in 1999 using a multi-stakeholder approach to address conflict over "interceptions" of fish—fish that originate in one country but are caught in the other (*see* Figure 9.5). At that time, the treaty also established a restoration and enhancement fund (Pacific Salmon Commission, 2016b) to support healthy salmon populations in both marine and freshwater environments. The agreement's focus on anadromous species illustrates how marine and freshwater linkages can be considered in a transboundary agreement. Joint recommendations put forward in 2018 for a new 10-year agreement explicitly acknowledge climate change and include provisions for long-term monitoring, science-based management, and renewed commitments to support conservation and sustainable-use opportunities for Indigenous, commercial and recreational fishers.

a)



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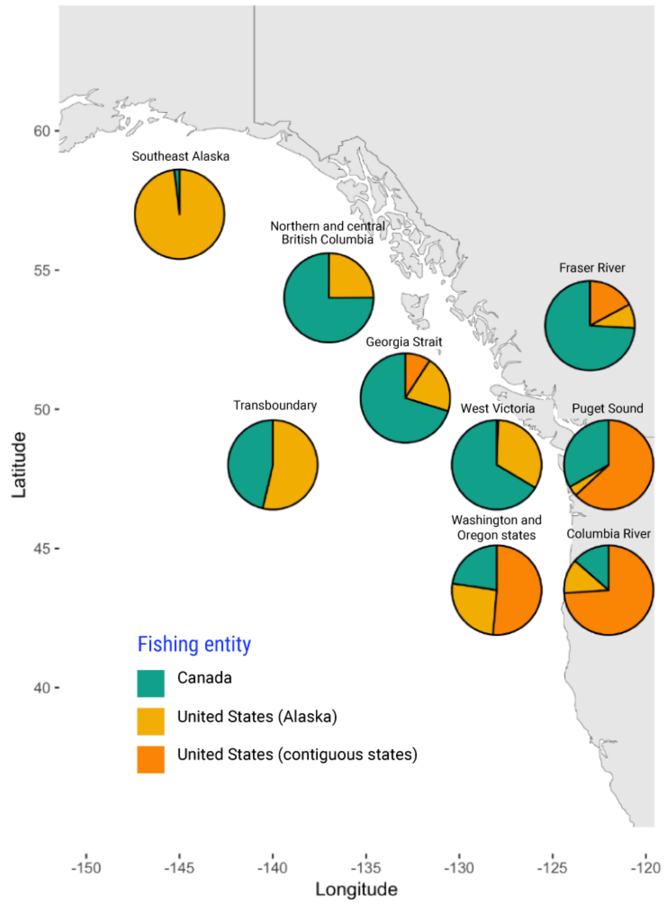


Figure 9.5: a) Migratory patterns of major Chinook salmon (*Oncorhynchus tshawytscha*) stock groups. Source: Adapted from the National Marine Fisheries Service, 2019. b) Average captures of regional Chinook salmon (*Oncorhynchus tshawytscha*) for the period 2009–2017 under managed fisheries of the Pacific Salmon Treaty. The values in the pie charts represent the proportion of each region's major chinook stock captured by individual fishing entities (averaged across regional stocks), and do not include escapement. Data source: Pacific Salmon Commission, 2019.

Further reading: McIntosh, 2016; Peterman et al., 2016; Temby et al., 2015; Criddle, 2012; McKinney et al., 2010; Munro et al., 1997; Miller, 1996; Munro and Stokes, 1989.

As a significant contributor to international environmental negotiations and global environmental governance (Stoett, 2018), Canada is well suited to promote adaptive and inclusive transboundary resource management solutions. Most of Canada's marine and freshwater agreements already observe widely accepted principles, such as the duty to cooperate, no-harm and equitable use (Koubrak and VanderZwaag 2020; Paisley, 2002; United Nations, 1970). Additionally, access to some of the world's largest anadromous fish stocks puts Canada in a unique position to champion integrated marine and freshwater management in transboundary systems. An overarching climate change adaptation goal for transboundary resources is to develop management institutions capable of responding to increased variability while still sustaining shared benefits in the long term. The following sections introduce challenges that climate change presents to shared governance of transboundary marine and freshwater resources and outline opportunities for adaptation.

9.3.2 Marine agreements

Canada is bordered by three oceans whose marine resources provide important ecological, social, economic and cultural benefits (Cisneros-Montemayor et al., 2017; Ommer, 2007; Nuttall, 2005; Fisheries and Oceans Canada, 2002). In 2016, British Columbia's exports of Pacific hake (*Merluccius productus*), Chinook salmon (*Oncorhynchus tshawytscha*) and Pacific halibut (*Hippoglossus stenolepis*) alone—all shared marine resources—accounted for $161.6 million (Government of British Columbia, 2017).

Changing ocean conditions due to climate change have led to substantial geographic shifts in marine animals, a pattern expected to continue or accelerate in the future. With rising ocean temperatures, marine species are already shifting poleward (Palacios-Abrantes et al., 2020a; Pinsky et al., 2018; Poloczanska et al., 2016; Weatherdon et al., 2016; Cheung et al., 2015; García Molinos et al., 2015; Kintisch, 2015; Peterson et al., 2015; Pinsky et al., 2013; Poloczanska et al., 2013; Fogarty, 2012) or into deeper water (Dulvy et al., 2008) to stay within their preferred temperature range. Movements can be temporary; for example, greater proportions of Pacific hake (whiting) migrated northward into Canadian waters during the warm 1998 and 2015 El Niño events (Berger et al., 2017). Shifts are also associated with ecological responses and altered food-web interactions that increase uncertainty about stock productivity and the vulnerability of fish to pollution and exploitation (Cheung, 2018; Cheung et al., 2016; Cheung et al., 2015; Doney et al., 2012; Gruber et al., 2012; Ainsworth et al., 2011; Perry et al., 2005).

Because the movement of fish stocks across international borders redistributes shared marine resources (*see* Figure 9.6), it challenges existing cooperative governance structures (*see* Table 9.3). Uncertainty surrounding this redistribution modifies the relatively static management context under which contractual and reciprocal rights and responsibilities were originally agreed (Gullestad et al., 2020; Hannesson, 2020; Mendehall et al., 2020; Østhagen et al., 2020; Palacios-Abrantes et al., 2020a, b; Bindoff et al., 2019; Wenar, 2015; Mills et al., 2013; Ringius et al., 2002; United Nations, 1970), potentially accentuating disagreements over fisheries allocations (Pinsky et al., 2018; Spijkers and Boonstra, 2017; Berkes, 2010). Uncertainty about the magnitude and timing of climate-mediated changes also makes it harder to collaboratively develop and implement clear and pragmatic transboundary policies (Engler, 2020; Pecl et al., 2017; Hollowed et al., 2013; Polasky et al., 2011; Miller et al., 2010; Brander, 2007; Miller, 2007).

Table 9.3: Agreements to which Canada is a member that deal with transboundary stocks

AGREEMENT	OCEAN	MEMBERS (CURRENT NUMBER OF MEMBERS)	SPECIES	NUMBER OF SPECIES / SPECIES GROUPS
Convention for the Preservation of the Halibut Fishery of the Northern Pacific Ocean and Bering Sea	Pacific	Canada and the United States (2)	Pacific halibut	1
Pacific Salmon Treaty	Pacific	Canada and the United States (2)	Pacific salmon: chum, chinook, coho, pink, and sockeye	5
Pacific Whiting Treaty	Pacific	Canada and the United States (2)	Pacific hake	1
Convention on Cooperation in the Northwest Atlantic Fisheries	Atlantic	Iceland, Japan, the Republic of Korea, Norway, the Russian Federation, Ukraine, Canada, Cuba, Denmark (Faroe Islands and Greenland), the European Union, France (Saint-Pierre et Miquelon) and the United States (12)	Atlantic cod, redfish, American plaice, yellowtail flounder, witch flounder, white hake, capelin, thorny skate, Greenland halibut, shortfin squid, Northern shrimp	11*
Convention for the Conservation of Salmon in the North Atlantic Ocean	Atlantic	Canada, Denmark (Faroe Islands and Greenland), the European Union, Norway, the Russian Federation and the United States (6)	Atlantic salmon	1

AGREEMENT	OCEAN	MEMBERS (CURRENT NUMBER OF MEMBERS)	SPECIES	NUMBER OF SPECIES / SPECIES GROUPS
Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean	Pacific	Canada, Japan, the Russian Federation, the Republic of Korea and the United States (5)	chum salmon, coho salmon, pink salmon, sockeye salmon, chinook salmon, cherry salmon and steelhead trout	7

*The North Atlantic Fisheries Organization's Convention on Cooperation in the Northwest Atlantic Fisheries applies to most fisheries resources of the Northwest Atlantic, with the exception of salmon, tuna/marlin, whales, and sedentary species. However, it officially manages only 11 species (and 19 stocks).

These challenges provide impetus to develop cooperative adaptation strategies for the responsible stewardship of shared resources. For example, enhancing collaborative monitoring and integrating multiple data streams into seamless transboundary datasets can support more effective and precautionary management, and enable better enforcement of transboundary marine agreements (Pinsky et al., 2021, 2018; Wendebourg, 2020; Aquorau et al., 2018; Mills et al., 2013; Link et al., 2011; McIlgorm et al., 2010). Greater responsiveness in management regimes would facilitate such developments (Bailey et al., 2016; Favaro et al., 2012), such as that being implemented by the Transboundary Resources Assessment Committee (TRAC), which is conducting and reviewing stock assessments and projections to support management of shared Eastern Georges Bank cod, haddock and yellowtail flounder across the Canada–U.S. boundary in the Gulf of Maine–Georges Bank region (Palacios Abrantes et al., 2020b).

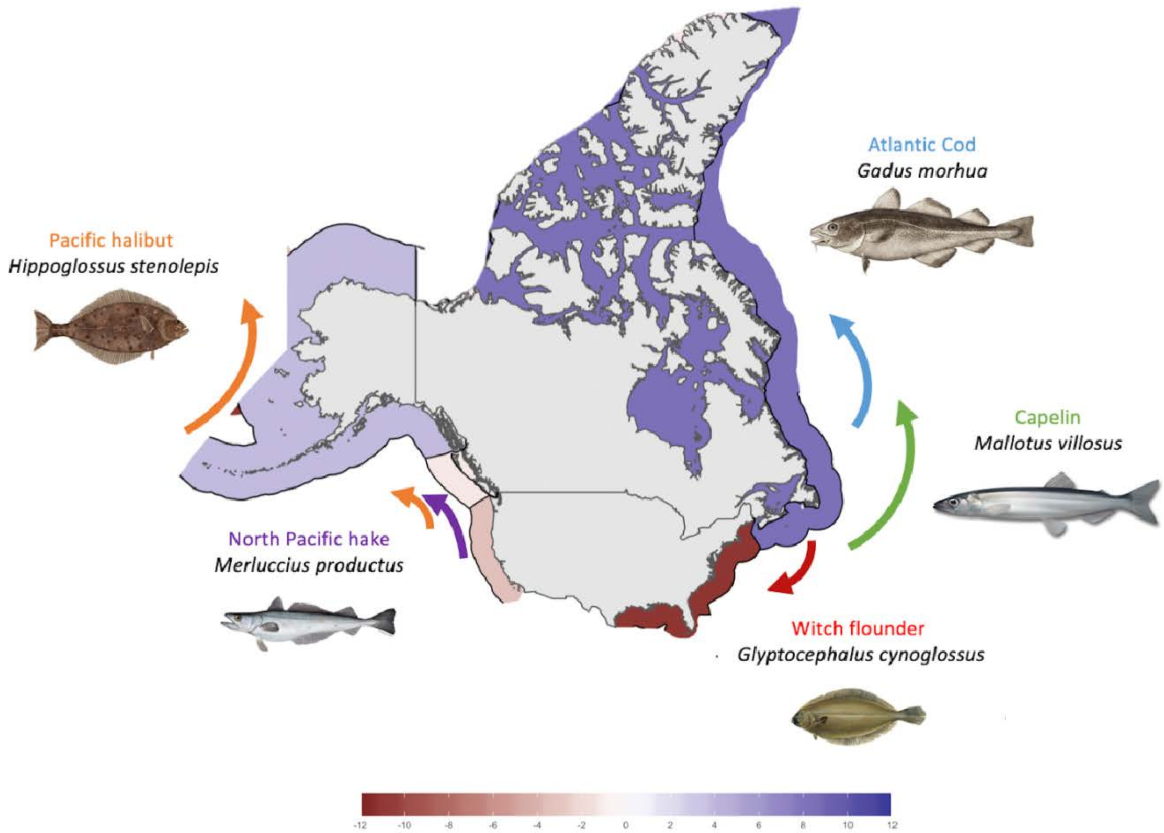


Figure 9.6: Map of projected shifts in the distribution of representative commercial transboundary fish species targeted by American and Canadian fisheries by 2050 under a high emissions scenario, relative to 2014. The coloured scale indicates the projected change in catch shares within the Exclusive Economic Zone (red = decline; purple = increase). The arrows on the map represent the direction of the shift in distribution for these five key fish species. Source: Adapted from Cheung et al., 2016.

To be effective, agreements also need to respond to shifts in societal norms (Stoett, 2018), such as the growing importance of accounting for equity and the unique rights of Indigenous people (Campbell, 2015; Dodds and Hemmings, 2015). Various strategies can support the development of transboundary marine agreements in ways that meet objectives adaptively while striving for equity. Key tools include fishing permit structures that facilitate entry into different/emerging fisheries, sustained monitoring at change-relevant scales, and catch limits or schemes that provide for capacity adjustments (e.g., license buy-back or tradable quota shares) (Aqorau et al., 2018; Mills et al., 2013). Also critical is meaningful participation of Indigenous peoples in negotiations and the inclusion of Indigenous ecological knowledge in the development of more adaptive strategies (Ojea et al., 2020; Armitage et al., 2015; Mills et al., 2015; Aswani and Lauer, 2014). Increasing the capacity of Indigenous communities and stakeholder groups to independently apply risk-based tools is one way to strengthen the role of these groups in transboundary decision-making (Le Bris et al., 2018; Payne et al., 2017; Mills et al., 2015).

9.3.3 Freshwater agreements

As with other Canadian river basins, changes in precipitation and snowpack, shifts in the timing and shape of annual hydrographs, water temperature increases, and increased frequency of floods and droughts (*see* Water Resources chapter) present challenges to the management of transboundary waters. These impacts will vary across the country (*see* Figure 9.7) and will test cooperative water relations by increasing the need for difficult trade-offs across competing freshwater uses, such as hydropower production, irrigation, flood control, recreation, navigation, and species conservation (Cooley et al., 2012; Cooley and Gleick, 2011; Hamlet, 2010; Cooley et al., 2009; Bruce et al., 2003). These uses form the basis of shared management considerations across the Canada–U.S. border, with climate change affecting Canada–U.S. hydro-relations differently depending on which shared management considerations are under threat (*see* Table 9.4). In addition, the effects of other non-climate stressors like increasing demand for electricity, misaligned domestic conservation laws in Canada and the United States, industrial and agricultural pollution, invasive species and increased water consumption will be amplified by climate change, further affecting cooperative relations.

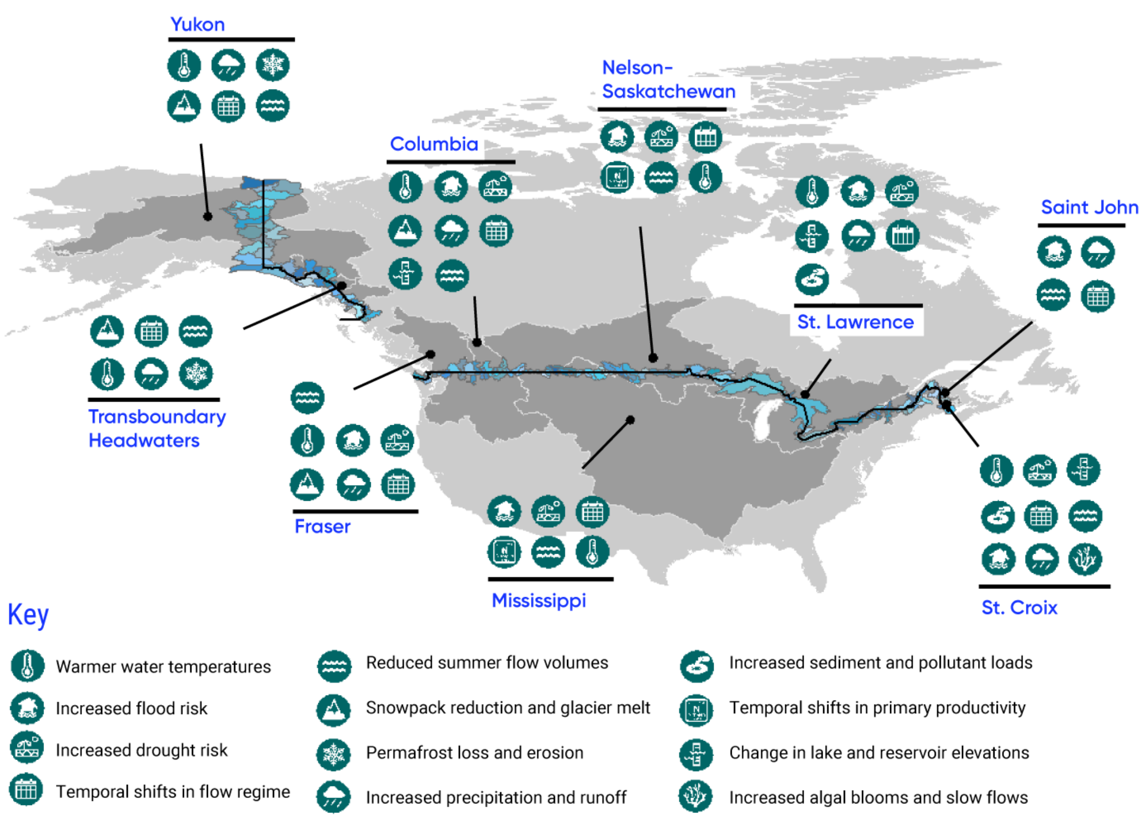


Figure 9.7: Projected climate change impacts for major drainage basins that are shared across Canada–US borders. Data sources: Adapted from George, 2019b; International Joint Commission, 2017; World Wildlife Fund-Canada, 2017; Bartolai et al., 2015; International Joint Commission, 2013; Shrestha et al., 2012; Hamlet, 2010; Mantua et al., 2010; International Joint Commission, 2009; Hamlet and Lettenmaier, 2007; Bruce et al., 2003; Hamlet and Lettenmaier, 1999.

Table 9.4: Shared management considerations, related climate change stressors and major shared drainage basins affected

SHARED MANAGEMENT CONSIDERATIONS	RELATED CLIMATE CHANGE STRESSORS	MAJOR SHARED DRAINAGE BASINS AFFECTED
Drinking water supply		• Fraser • St. Croix
Flood management		• Columbia • Fraser • Nelson-Saskatchewan • St. Lawrence
Fish conservation		• Columbia • Fraser • Nelson-Saskatchewan • St. Croix • St. Lawrence • Transboundary Headwater • Yukon
Hydropower production		• Columbia • Saint John • St. Croix • St. Lawrence
Agricultural irrigation		• Columbia • Nelson-Saskatchewan • Mississippi
Shipping and navigation		• Columbia • St. Lawrence

SHARED MANAGEMENT CONSIDERATIONS	RELATED CLIMATE CHANGE STRESSORS	MAJOR SHARED DRAINAGE BASINS AFFECTED
Recreation opportunities		• Columbia • St. Lawrence
Water quality management		• Columbia • Fraser • Nelson-Saskatchewan • Saint John • St. Lawrence • Transboundary Headwaters

Key

- Warmer water temperatures
- Increased flood risk
- Increased drought risk
- Increase precipitation and runoff
- Reduced summer flow volumes
- Snowpack reduction and glacier melt
- Permafrost loss and erosion
- Temportal shifts in flow regime
- Increased sediment and pollutant loads
- Temporal shifts in primary productivity
- Change in lake and reservoir elevations
- Increased algal blooms and slow flows

Sources: International Joint Commission, 2020; Province of British Columbia and State of Alaska, 2015; Canada and U.S.A., 2013; Province of British Columbia and State of Montana, 2010; Norman and Bakker, 2005; State of Illinois et al., 2005; Great Lakes Commission, 1994; Province of British Columbia and State of Washington, 1992; Canada and U.S.A., 1985; Province of Ontario et al., 1985; Canada and U.S.A., 1964; Canada and U.S.A., 1954; Canada and U.S.A., 1952; Canada and U.S.A., 1950; Canada and U.S.A., 1932; Canada and U.S.A., 1925; Great Britain and U.S.A., 1909.

Freshwater governance across the Canada–U.S. border is defined by numerous transboundary agreements at federal and provincial/state levels (*see* Table 9.5). Several of these agreements were signed before climate change was a recognized issue and remain grounded in assumptions of stationarity (e.g., Boundary Waters Treaty, Columbia River Treaty and Convention on Great Lakes Fisheries).

Table 9.5: Transboundary freshwater agreements across the Canada–U.S. border with key water bodies indicated

MAJOR DRAINAGE BASIN	AGREEMENTS	KEY WATER BODIES
Yukon	• Pacific Salmon Treaty 1985 (federal) • Boundary Waters Treaty 1909 (federal)	• Yukon River
Transboundary Headwaters	• Pacific Salmon Treaty 1985 (federal) • Boundary Waters Treaty 1909 (federal) • BC-Alaska Memorandum of Understanding and Cooperation 2015 (provincial/state)	• Stikine River • Alsek River • Chilkat River • Taku River • Whiting River • Unuk River
Fraser	• Pacific Salmon Treaty 1985 (federal) • BC-Washington Environmental Cooperation Agreement 1992 (provincial/state)	• Fraser River • Abbotsford-Sumas Aquifer • Nooksak River
Skagit	• Boundary Waters Treaty 1909 (federal)	• Skagit River
Columbia	• Boundary Waters Treaty 1909 (federal) • Columbia River Treaty 1964 (federal) • Flathead Memorandum of Understanding and Cooperation on Environmental Protection, Climate Action and Energy 2010 (provincial/state) • BC-Washington Environmental Cooperation Agreement 1992 (provincial/state)	• Columbia River • Kootenay River • Osoyoos Lake • Flathead River

MAJOR DRAINAGE BASIN	AGREEMENTS	KEY WATER BODIES
Nelson-Saskatchewan	• Boundary Waters Treaty 1909 (federal)	• Souris River • Red River
Mississippi	• Boundary Waters Treaty 1909 (federal)	• Saint Mary River • Milk River • Poplar River
St. Lawrence	• Boundary Waters Treaty 1909 (federal) • Great Lakes Water Quality Agreement 2012 (federal) • Convention on Great Lakes Fisheries 1954 (federal) • Lake of the Woods Convention & Protocol 1925, 1979 (federal) • Saint Lawrence Seaway Project Agreement 1952, 1954 (federal) • Niagara River Water Diversion Treaty 1950 (federal) • Saint Lawrence Deep Waterway Treaty 1932 (federal) • Great Lakes Charter 1985 (provincial/state) • Ecosystems Charter for the Great Lakes and Saint Lawrence Basin 1994 (provincial/state) • Lake Memphremagog Environmental Cooperation Agreement 1989, 2003 (provincial/state) • The Great Lakes–St. Lawrence River Basin Sustainable Water Resource Agreement 2005 (provincial/state)	• Great Lakes • St. Lawrence River • Lake of the Woods • Rainy River • Lake Champlain • Richelieu River • Lake Memphremagog • Niagara River
Saint John	• Boundary Waters Treaty 1909 (federal)	• Saint John River

MAJOR DRAINAGE BASIN	AGREEMENTS	KEY WATER BODIES
St. Croix	• Boundary Waters Treaty 1909 (federal)	• St. Croix River

Sources: International Joint Commission, 2020; Province of British Columbia and State of Alaska, 2015; Canada and U.S.A., 2013; Province of British Columbia and State of Montana, 2010; Norman and Bakker, 2005; State of Illinois et al., 2005; Great Lakes Commission, 1994; Province of British Columbia and State of Washington, 1992; Canada and U.S.A., 1985; Province of Ontario et al., 1985; Canada and U.S.A., 1964; Canada and U.S.A., 1954; Canada and U.S.A., 1952; Canada and U.S.A.,1950; Canada and U.S.A., 1932; Canada and U.S.A., 1925; Great Britain and U.S.A., 1909.

Other countries can provide useful lessons for updating Canada–U.S. freshwater agreements. In 2015, under the United Nations Economic Commission for Europe's (UNECE) Water Convention, Belarus, Lithuania and Russia jointly created one of the first frameworks for climate change adaptation in a transboundary river basin—the Strategic Framework for Adaptation to Climate Change in the Neman River Basin (Korneev et al., 2015). The Neman Basin's primary environmental stressor is industrial pollution. Unless adaptation measures are put in place, industrial pollutants will become more concentrated as runoff decreases due to climate change. The Framework establishes a baseline status for basin-wide water monitoring and includes a common set of spatially explicit impact and risk projections. The agreement is closely aligned with the principles laid out in the EU Water Framework Directive, with adaptive features including "climate-proof" performance measures for monitoring that are capable of responding to non-stationarity (e.g., proportional rather than volumetric); a cyclical approach with periodic revisions to accommodate new developments in science and technology, address new uncertainties, and permit adjustment as existing uncertainties are resolved; the establishment of a river basin commission with multi-stakeholder representation capable of responding to shifting interests and priorities of affected parties as the impacts of climate change unfold; and consistent policy linkages across local, national and international levels that allow decision makers to be more agile, reducing bottlenecks from poor policy harmonization (European Commission, 2009).

Table 9.6 lists adaptive measures implemented in transboundary river basins globally and compares these with measures applied in key Canada–U.S. freshwater agreements. Except for the Great Lakes Water Quality Agreement (GLWQA), no more than a third of these measures are currently applied in any of Canada's major shared river basins. The Canada–U.S. International Joint Commission (IJC) has developed a high-level non-binding framework for its seventeen Boards and Committees, which lays out a process for climate change adaptation planning, knowledge sharing, and the use of adaptive management (International Joint Commission, 2018; Bernstein et al. 2017). The GLWQA was updated in 2012 and is currently Canada's most climate-ready freshwater treaty. The agreement explicitly includes obligations to apply adaptive management principles in response to climate change, but implementation has been slow. There remains no jointly developed basin-wide strategy for addressing climate change impacts (International Joint Commission, 2017).

Table 9.6: Adaptive practices applied in transboundary freshwater agreements (globally), compared with current practices under key Canada–U.S. freshwater agreements

TRANSBOUNDARY ADAPTIVE PRACTICES IN BASINS (GLOBALLY)	BOUNDARY WATERS TREATY	IJC* INITIATIVES UNDER BOUNDARY WATERS TREATY	PACIFIC SALMON TREATY	COLUMBIA RIVER TREATY	GREAT LAKES WATER QUALITY AGREEMENT	CONVENTION OF GREAT LAKES FISHERIES
Environmental						
Joint habitat quality targets (e.g., ecological flows)			■	■	■	
Flexible water quality standards and/or operating rules (e.g., proportional not volumetric allocations)						
"Climate-proof" performance measures for joint monitoring						
Coordinated flood, drought, and/or pollution management and early warning systems		■		■	■	
Ecological management units (e.g., river basin)		■	■	■	■	■
Integrated adaptive management (systems-based, including marine systems; test hypotheses to address uncertainties)					■	
Coordinated climate change modelling, analyses, and research		■			■	

TRANSBOUNDARY ADAPTIVE PRACTICES IN BASINS (GLOBALLY)	BOUNDARY WATERS TREATY	IJC* INITIATIVES UNDER BOUNDARY WATERS TREATY	PACIFIC SALMON TREATY	COLUMBIA RIVER TREATY	GREAT LAKES WATER QUALITY AGREEMENT	CONVENTION OF GREAT LAKES FISHERIES
Political/Governance						
Federal ratification of international policies laws for water management (e.g., Water Convention)						
Climate change adaptation obligations embedded explicitly in agreement					■	
Allowance for supplementary agreements				■		
Dispute resolution mechanisms	■	■		■	■	
Formal river basin organization(s) that include or consult with multiple interest groups	■		■		■	■
Explicit commitment to develop joint climate change adaptation management plan/framework					■	
Policy harmonization across borders and levels of government						
Frequent (e.g., 10–20 year) periodic review/revision of agreement					■	■
Open data sharing across multiple interest groups		■	■		■	

TRANSBOUNDARY ADAPTIVE PRACTICES IN BASINS (GLOBALLY)	BOUNDARY WATERS TREATY	IJC* INITIATIVES UNDER BOUNDARY WATERS TREATY	PACIFIC SALMON TREATY	COLUMBIA RIVER TREATY	GREAT LAKES WATER QUALITY AGREEMENT	CONVENTION OF GREAT LAKES FISHERIES
Economic						
Joint financial commitment to climate change adaptation					■	
Equitable sharing of benefits (e.g., payments for upstream ecosystem services)			■	■		

*The International Joint Commission (IJC)

Sources: UN Economic Commission for Europe, 2018; Escribano Francés et al., 2017; Honkonen, 2017; International Joint Commission, 2017; Bartolai et al., 2015; Norman, 2015; UN Economic Commission for Europe et al., 2015; Abdel-Fattah and Krantzberg, 2014; BC Hydro, 2013; Canada and U.S.A., 2013; Hamlet et al., 2013; International Joint Commission, 2013; UN Economic Commission for Europe, 2013; Bankes and Cosens, 2012; Cooley et al., 2012; Shrestha et al., 2012; Cooley and Gleick, 2011; UN Development Programme - Global Environmental Facility, 2011; Hamlet, 2010; Keskitalo, 2010; Mantua et al., 2010; Northwest Power and Conservation Council, 2010; Brown and Crawford, 2009; Cooley et al., 2009; de Loë, 2009; Huitema et al.. 2009; International Joint Commission, 2009; Pahl-Wostl et al., 2009; Timmerman and Bernardini, 2009; UN Economic Commission for Europe, 2009; Krysanova et al., 2008; Draper and Kundell, 2007; Hamlet and Lettenmaier, 2007; Ketchum and Barroso, 2006; Sneddon and Fox, 2006; Norman and Bakker, 2005; Bruce et al., 2003; Dietz et al., 2003; Muckleston, 2003; Paisley, 2002; Hamlet and Lettenmaier, 1999; Johnson, 1999; Wolf, 1998; Lee, 1994; Stoner et al., 1993; Canada and U.S.A., 1985; Blumm, 1980; Canada and U.S.A., 1964; Canada and U.S.A., 1954; Great Britain and U.S.A., 1909; Yukon River Panel, n.d.

The need for climate change adaptation, therefore, presents opportunities to modernize arrangements governing Canada's shared river basins in order to provide more resilient frameworks for coping with uncertainty, protecting environmental values and improving representation of affected groups and Indigenous governments. Review and revision of existing arrangements, as is currently occurring for the Columbia River Treaty, can aid in addressing adaptation gaps (*see* Case Story 9.3).

Case Story 9.3: Modernizing the Canada–U.S. Columbia River Treaty to consider climate change

The 1964 Canada–U.S. Columbia River Treaty (CRT) outlines rules for cooperative uses and responsibilities over hydropower production and flood management (Canada and U.S.A., 1964). The agreement was once an exemplar of international water cooperation due to its observance of the principle of "equitable use" via a 50/50 split of hydropower benefits (Paisley, 2002). Adaptive features also include the annual creation of two operating plans covering different planning horizons (upcoming year and six years out) and the use of sub-agreements. Additional shared values in the basin include recreation, navigation, agricultural irrigation and Indigenous cultural heritage (Government of British Columbia, 2013). The agreement is now outdated because it makes no explicit mention of these other values, assumes stationarity and lacks mechanisms for interested parties to be included in decision-making. Climate change projections show an increasing proportional contribution of Columbia River flows to the Canadian part of the basin, which will likely increase U.S. demand for Canadian water management (*see* Figure 9.8; Hamlet et al., 2013; Hamlet, 2010; Mantua et al., 2010; Hamlet and Lettenmaier, 2007; Hamlet and Lettenmaier, 1999). With the aim of better reflecting modern values, renegotiations of the CRT are currently underway. As part of the negotiations, ecosystem functions are being considered, modelled climate change projections are playing a role, and, in an unprecedented move for Canadian international negotiations, Indigenous communities have been included as observers at the negotiating table (Government of British Columbia, 2019; Government of British Columbia, 2014; U.S. Entity to the Columbia River Treaty, 2013). The extent to which the CRT will re-establish its status as an exemplar by embracing more adaptive principles remains to be seen, but the current policy window is an opportunity to re-craft a historic water agreement with an eye towards future climate uncertainty.

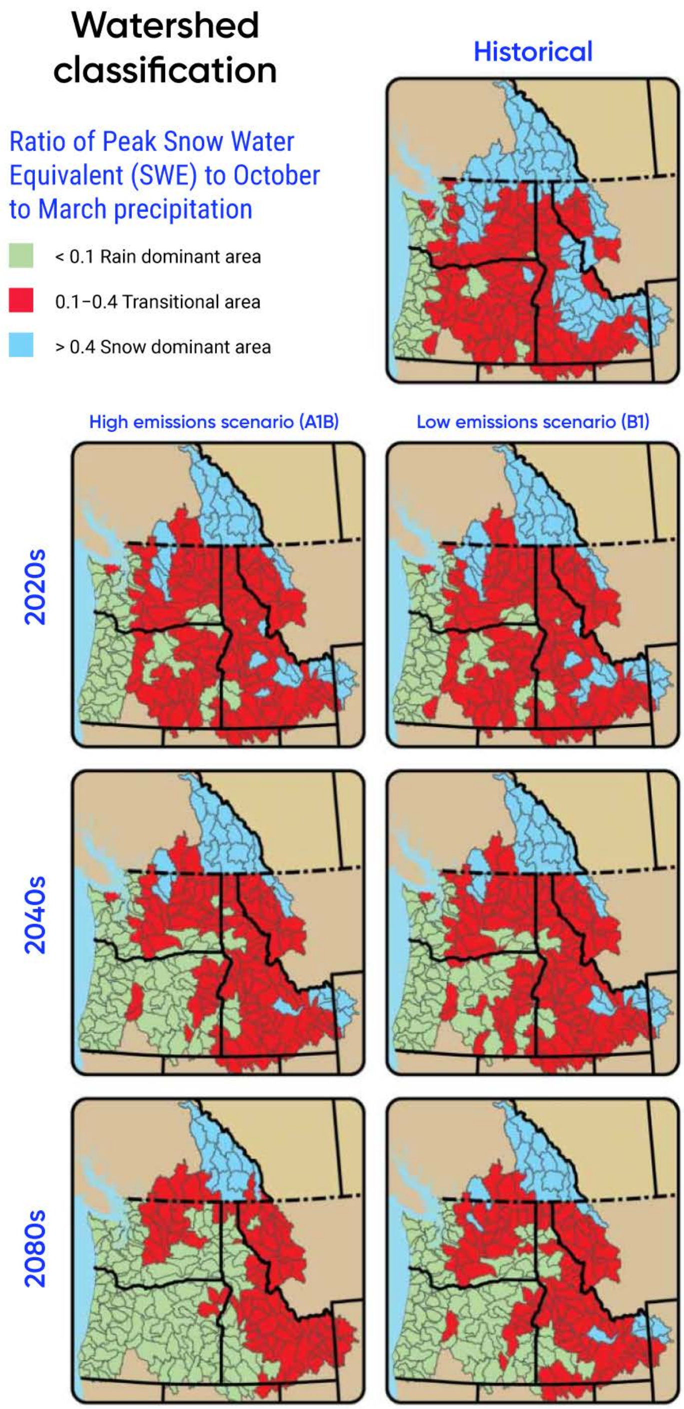


Figure 9.8: Historical and projected future watershed classifications for the Columbia Basin, based on the global emissions scenarios (the A1B relatively high emissions scenario and the B1 low emissions scenario) for the 2020s, 2040s and 2080s. As climate change progresses, 50% of the total reservoir storage is expected to lie in Canada. Canada is also expected to have an increasingly dominant portion of natural water storage as snowpack. Source: Adapted from Hamlet et al., 2013.

9.4 Climate change presents risks and opportunities for international trade

Canada is dependent on international trade and will increasingly experience economic effects from extreme weather and climate change impacts and adaptation elsewhere in the world, especially when occurring in countries with which Canada has strong trade ties.

Canada's mixed economy is reliant on trade as a source of wealth and to satisfy consumer needs. The impacts of climate change around the world, such as sea-level rise and more intense extreme events, as well as actions taken in response to these impacts will alter patterns of global trade, with consequences for Canadian businesses, consumers and the economy. Disruptions to supply and distribution networks, changes in the availability and price of traded goods, and the creation of global markets for new adaptation solutions are among the direct and indirect impacts of climate change. Weather-related disruptions to supply chains and short-term price spikes in staples heighten the need for Canadian firms and governments to assess the risks and opportunities that climate change impacts on global trade will present, including the negative effects of long-term adjustments in trade patterns for communities within and beyond Canada's borders. Little published research exists about these indirect impacts of climate change or assessments of action by Canadian businesses and governments to understand and manage resulting risks and opportunities.

9.4.1 Introduction

Canada relies on trade for economic and social well-being. Over half of the country's gross domestic product (GDP) derives from the export and import of goods and services in the global marketplace (Global Affairs Canada, 2019a). In 2018, Canada exported $706 billion and imported $753 billion in goods and services (Global Affairs Canada, 2019a), with goods accounting for just over 80% of trade by value. Five trade partners received 90% of Canada's exports and supplied over 85% of its imports in goods, with trade in consumer goods, energy and mining commodities particularly prominent, in dollar terms (*see* Figure 9.9). Although Ontario, Alberta and Quebec accounted for almost 80% of goods exported in 2017, exports originated from all provinces and territories (Global Affairs Canada, 2018). Ontario, Quebec and British Columbia received over 80% of imported goods in 2017. Every year, thousands of Canadian firms engage in international trade, with small- and medium-sized enterprises accounting for over 90% of trade activity, when measured by number of organizations. In dollar terms, large firms (over 500 employees) account for over 50% of trade value (Statistics Canada, 2018a, b).

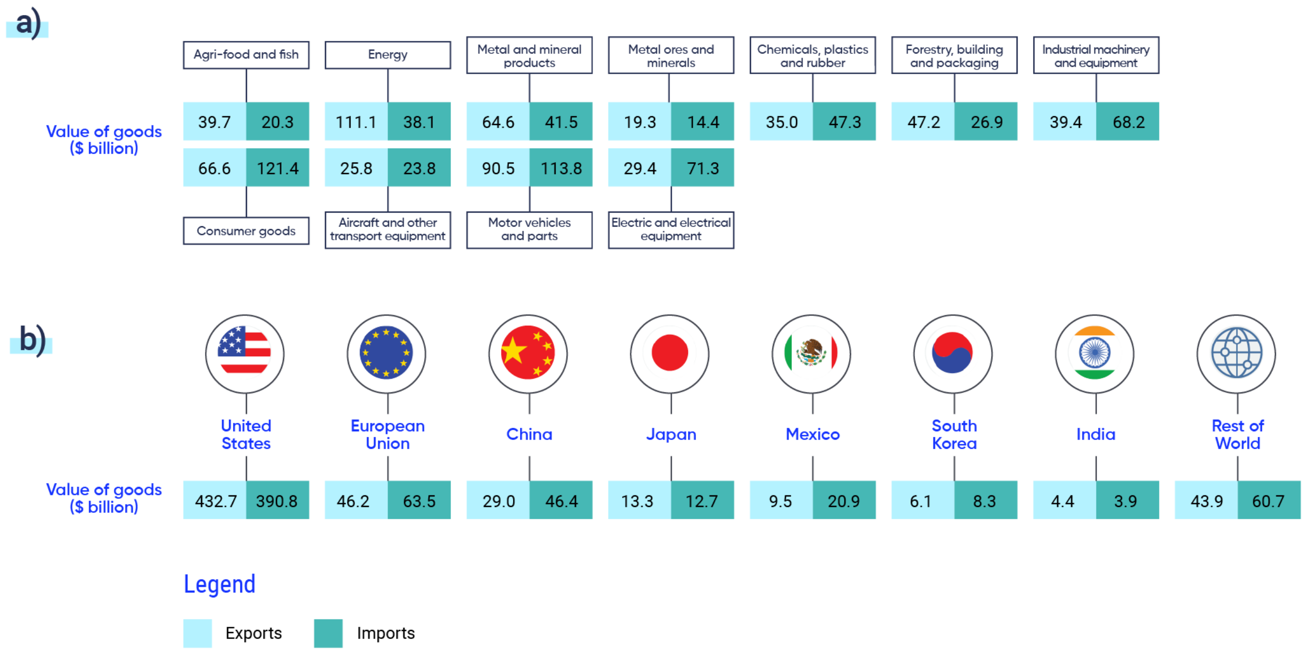


Figure 9.9: Canada's trade performance in 2018: a) value of exports (light blue) and imports (green) of goods in $ billions, by sector; b) Value of export (light blue) and import (green) of goods in $ billions, by trade partner or region. Source: Adapted from Global Affairs Canada, 2019a.

The impacts of climate change felt elsewhere in the world, such as increased temperatures, sea-level rise and more intense extreme events, have ripple effects for Canada's economy and population through international trade. As described elsewhere in this assessment, climate change impacts within Canada's borders shift the risks and opportunities faced by Canadian enterprises, with economy-wide consequences (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter and Sector Impacts and Adaptation chapter). Foreign enterprises competing with Canadian producers are exposed to climate change risks and opportunities in similar ways. Supply- and demand-side factors come into play, with benefits or costs tempered by the adaptive capacity at the enterprise, sector or country level (*see* Table 9.7).

Table 9.7: Examples of climate change risks and opportunities on the supply and demand sides of business

ADAPTIVE CAPACITY	PATHWAY OF EXPOSURE		EXAMPLES OF CLIMATE CHANGE-RELATED RISKS AND OPPORTUNITIES
Ability to adapt given size, resource endowments, geographic location, sector, policy and regulatory frameworks, information and partnerships	Supply	Infrastructure, capital goods and inventory	• Loss and damage from extreme events • Loss of coastal locations due to sea-level rise • Increased costs to pay for reconstruction and adaptation
		Employees and labour productivity	• Loss of hours worked due to disasters, infrastructure disruption, lack of access to workplace, temporary or permanent displacement • Loss of hours worked (or slower work) due to rising heat stress
		Supply chains and distribution networks	• Shortages of inputs (e.g., energy, water, food and other inputs) and disruptions in supply chains • Interruptions in delivery of goods and services to markets
		Products and services	• Changes in the cost of production and service delivery (e.g., increased input costs, increased cooling costs, higher insurance premiums)

ADAPTIVE CAPACITY	PATHWAY OF EXPOSURE		EXAMPLES OF CLIMATE CHANGE-RELATED RISKS AND OPPORTUNITIES
Ability to adapt given size, resource endowments, geographic location, sector, policy and regulatory frameworks, information and partnerships (continued)	Demand	Consumption / purchase	• Changes in quantity, quality or location of demand for goods and services
		Investment	• Changes in capital flows due to uncertainty of direct, indirect and cascading physical climate risks

Sources: Adapted from Batten, 2018; Surminski et al., 2018

In a global marketplace, countries and firms within them can specialize, producing goods and services for which they have a lower opportunity cost relative to foreign counterparts, while importing other goods and services. This principle—comparative advantage—is a key driver of international trade (Bruce and Haites, 2008). With the rise of emerging economies, trade flows and geographic centres of trade are expected to shift in the next few decades (Dellink et al., 2017). Producers in Atlantic Canada, for example, are forging connections with emerging Asian markets through the Suez Canal (Rapaport et al., 2017). Climate change stands to alter countries' comparative advantage (Costinot et al., 2014; Bruce and Haites, 2008) meaning that projected evolutions in world trade patterns may go unrealized (Dellink et al., 2017).

This section discusses the risks and opportunities to Canada from climate-induced disruptions to global supply chains and from changes in comparative advantage in a global marketplace. It also explores the interplay between climate change adaptation and international trade.

9.4.2 Trade and climate change risk

Climate change impacts can result in economic consequences for Canada by disrupting supply and distribution networks reliant on vulnerable trade infrastructure. Well-functioning transportation infrastructure is essential for trade. Globally, marine shipping and seaport operations account for about 80% of trade by volume and 70% by value (UN Conference on Trade and Development, 2018). Canada's transportation system moved $1.107 trillion in traded goods in 2017 (Transport Canada, 2017), with Port Metro Vancouver handling upward of 15% of the trade by value, with more than 160 countries (Nyland and Nodelman, 2017). International and Canadian Port authorities and operators indicate that weather and extreme climate events are already causing shipment delays and physical damage (UN Conference on Trade and Development, 2017; Ng et al., 2016). Changing climate conditions and extreme weather have numerous implications for seaports and land-based trade infrastructure (*see* Table 9.8), including disruptions that increase the cost of international trade and cause rerouting as firms opt for more reliable alternatives of the same mode or others (Dellink et al., 2017). Global food trade is particularly at risk because of a growing reliance on a small number of maritime, coastal and inland choke points to move food staples and fertilizers (Bailey and Wellesley, 2017).

Table 9.8: Examples of climate change risks for trade infrastructure

CLIMATE HAZARD	TRANSPORT MODE	EXAMPLES OF DIRECT IMPACTS	CONSEQUENCES ON TRADE INFRASTRUCTURE
Increased temperature and solar radiation	Road and rail	• Rail buckling • Pavement cracking • Loss of water seal causing potholing • Reduced life of asphalt	• Speed restrictions to avoid derailments • Increased maintenance and insurance costs
	Aviation	• Reduced life of asphalt • Reduced airlift capacity	• Increased maintenance and insurance costs • Need to construct longer runways to make up for reduced airlift
	Sea-based transport	• Reduced refrigeration capacity • Opening / expansion of Arctic shipping routes due to shrinking sea ice	• Increased need for cooling terminals and cargo • Reduced distances and time related to Arctic navigation, but need for additional navigation aids • Higher insurance costs for Arctic navigation

CLIMATE HAZARD	TRANSPORT MODE	EXAMPLES OF DIRECT IMPACTS	CONSEQUENCES ON TRADE INFRASTRUCTURE
Increased precipitation, inland flooding and fog intensity/duration	Road and rail	• Flooding • Bridge scour	• Increased maintenance and insurance costs • Rerouting to avoid affected roads and bridges
	Aviation	• Flooding of runways and access roads • Damage to facilities • Reduced visibility	• Increased maintenance and insurance costs
	Sea-based transport	• Damage to land infrastructure, cargo and equipment • Reduced capabilities in loading/unloading cargo at ports • Increased rates of asset deterioration (e.g., corrosion) • Reduced visibility in ships and by terminal operations	• Risk of delays • Increased construction and maintenance costs
Sea-level rise and storm surges	Road and rail	• Temporary or permanent inundation	• Increased maintenance and insurance costs • Risk of delays
	Aviation	• Temporary or permanent inundation	• Higher maintenance and insurance costs • Relocation

CLIMATE HAZARD	TRANSPORT MODE	EXAMPLES OF DIRECT IMPACTS	CONSEQUENCES ON TRADE INFRASTRUCTURE
Sea-level rise and storm surges (continued)	Sea-based transport	• Lower clearance under waterway bridges • Damage to port infrastructure • Increased rates of asset deterioration (e.g., corrosion)	• Need for new ship design • Need for reconfiguration of operational areas • Increased maintenance costs and repair of port facilities
Extreme weather (e.g., high winds, storms)	Road and rail	• Disturbance to transport electronic infrastructure (e.g., signalling)	• Disruption to operations • Increased maintenance and insurance costs
	Aviation	• Disturbance to transport electronic infrastructure (e.g., signalling)	• Increased maintenance and insurance costs • Risk of delays
	Sea-based transport	• Temporary shutdown of ports • Worsened sailing conditions • Disturbance to transport electronic infrastructure (e.g., signalling)	• Risk of delays • Increased maintenance and insurance costs

Sources: Dellink et al., 2017; UN Conference on Trade and Development, 2017

Although direct impacts on international trade such as these will occur and potentially intensify with climate change, their consequences are uncertain. Statistical analyses of bilateral trade activity at a global level show that temperature rise and the occurrence of climate-related disasters reduce trade flows, partly because of increased transportation costs (Dallmann, 2019; Oh, 2017). Distance between trade partners, each country's socioeconomic status and strength of institutions shape vulnerability. One global study shows that sea-level rise consistent with a scenario of high global emissions will decrease the performance of sea transport worldwide by 2050 in terms of cargo handling capacity, reducing exports and economic welfare in all 13 regions modelled (Chatzivasileiadis et al., 2016). Another study suggests that disruptions to trade infrastructure due to climate events by 2060 could cause major economic consequences in specific regions, but may not be as pronounced as price and production adjustments induced by climate impacts (Dellink et al., 2017). Critical uncertainties in assessing the impact of climate change on trade infrastructure include the viability of Arctic shipping, the resilience of newly built and existing trade infrastructure and operators' levels of preparedness (The Economist, 2020; Food and Agriculture Organization, 2018; Becker et al., 2017; Dellink et al., 2017; Chatzivasileiadis et al., 2016). Canada's transport infrastructure, including trade infrastructure (Great Lakes–St. Lawrence Seaway, Port Metro Vancouver and Port Saint John), is vulnerable to climate-related damage and disruptions, with efforts to understand and manage future impacts still in early stages (Palko, 2017).

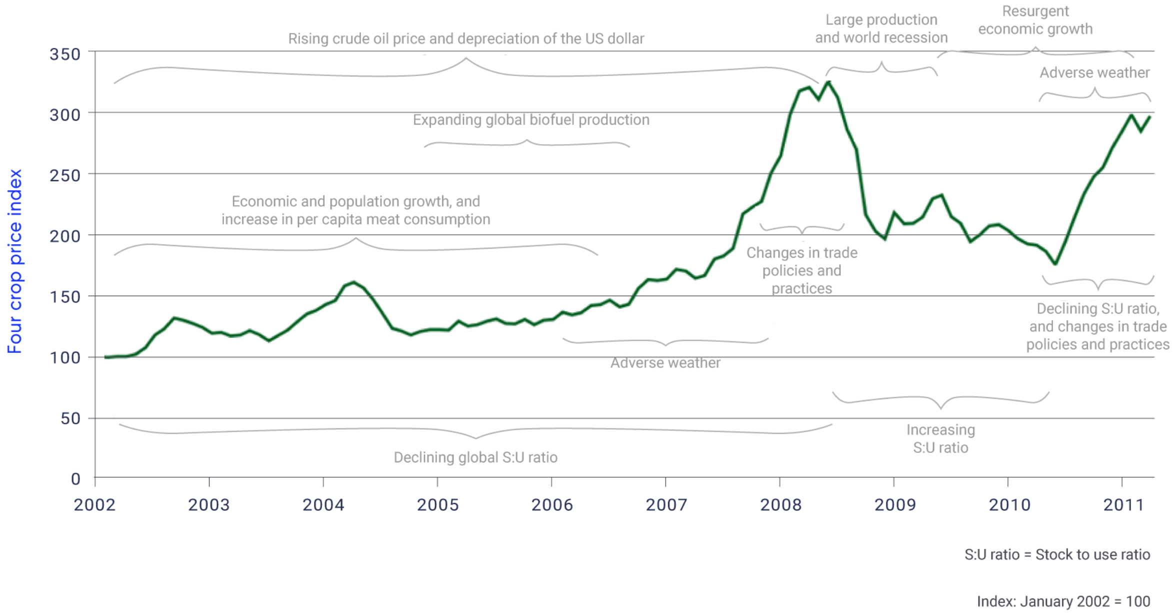
Indirect impacts of climate change on trade include shifts in the availability and prices of food and feedstock, timber, metals and other basic goods and services in the global marketplace. International trade comprises an increasingly complex, interdependent network of global supply chains, such that climate-induced disruptions to production can have economic ripple effects across sectors and geographies over the short and long term (Adams et al., 2020; Dellink et al., 2017; Wenz and Leverman, 2016). On the supply side, exposure to climate change impacts and the degree of concentration of suppliers are key risk factors (Gledhill et al., n.d.). Canada is among the top five global suppliers of wheat, fertilizer, petroleum and metal ores and top ten of corn (Bailey and Wellesley, 2017; Gledhill et al., n.d.). On the demand side, dependency and buffering capacity in local markets are among the traits that shape vulnerability to shocks (D'Amour et al., 2016; Wenz and Leverman, 2016). Climate-related disruptions in wheat, corn, rice and soybeans (so-called agricultural commodities or food staples) to major suppliers can affect global prices. Supply- and demand-side factors interact in complex ways. For example, drought conditions and heat waves in 2010 and 2011 in Russia and other supply regions reduced wheat yields and global food production, and, combined with market and policy responses (e.g., export bans), contributed to a spike in prices for wheat globally, as well as food insecurity and social unrest across the Middle East (*see* Box 9.2; Challinor et al., 2017; D'Amour et al., 2016; Coulibaly, 2013). In contrast to food staples, energy and mining supplies are more diversified and disruptions are more likely to relate to non-climate factors, such as resource availability, technological advances and politics (Goldstein et al., 2019; Gledhill, n.d.). The global COVID-19 pandemic highlights the vulnerability of Canadian manufacturing sectors to disruptions in international supply chains, due to their reliance on foreign suppliers for inputs and foreign sales (Global Affairs Canada, 2020).

Box 9.2: Climate, global spikes in food prices and domestic impacts

The price of food staples or commodities (grains, oilseeds, vegetable oils, meat, seafood, sugar and fruit) can rise and fall abruptly. In the past 40 years, five periods of price volatility have occurred. In the aftermath of price spikes, markets adjust and prices typically return to within historic levels (Trostle, 2011). However, food price spikes—even for a short term—and new price plateaus have social consequences. Price spikes in commodities are particularly concerning for developing countries dependent on imported staples for nutrition and calories. Countries in Northern Africa and the Middle East, for example, depend strongly on imported wheat and consumer diets rely on its steady supply (D'Amour et al., 2016). A drop in global stocks of commodities combined with higher prices can outstrip a country's financial capacity to import the food needed to satisfy domestic consumption.

Sharp food price spikes occurred in 2007–2008 and 2010–2011, reflecting a combination of long-term factors and short-term shocks (Trostle, 2011). The price of food staples has seen a general rise since 2002 due to both consumption and production-related factors, including population growth, higher per-capita incomes, increased consumption of animal products, exchange rates, rising energy prices, land-use conflicts due to a rise in global biofuel production and slower growth in agricultural productivity. Added to these long-term trends, short-term shocks drove price spikes in 2007–2008 and 2010–2011. Shortfalls in production caused by severe weather events, a drop in world stocks of grains and oilseeds and changes in trade policies and practices (e.g., export bans and lifting of import levies) were the main short-term factors contributing to price spikes in both time periods, although the importance and sequencing of these factors differed (*see* Figure 9.10a). As a major wheat producer, crop losses in Canada due to wet weather in 2010 was one among several adverse weather events contributing to global food price spikes (*see* Figure 9.10b).

a)



b)

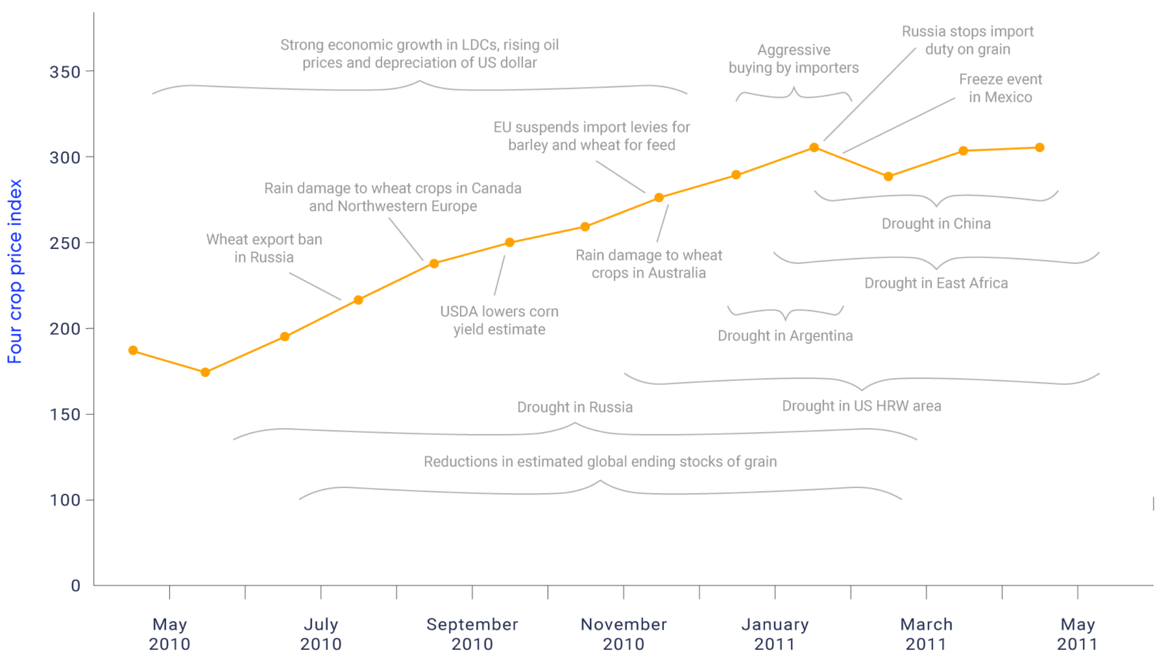


Figure 9.10: Primary factors contributing to increases in global food prices, based on a four-crop price index (wheat, rice, corn and soybean). a) Shows the change in crop prices (green line) for the period 2002–2011, and identifies long-term and short-term factors that contributed to price changes over time. Tighter supply-demand balances (as depicted by global stock-to-use ratio “S:U ratio”) and economic growth/recession, for example, are a backdrop to weather events and trade policies. b) Change in crop prices between May 2010 and April 2011 in relation to weather-related events that resulted in supply shortfalls. Both wet and dry conditions, which were not isolated to one global region, contributed to a reduction in global crop supply. Source: Adapted from Trostle, 2011.

As a trading nation, Canada is not immune to the influence of global spikes in food staples. Food prices in Canada, as measured by the Consumer Price Index (CPI), increased markedly between 2007 and 2012 (Rollin, 2013). The CPI measures changes in prices by tracking the cost of a fixed basket of goods and services through time, with food as one of eight items captured in the CPI. Between 2007 and 2012, the food component of the CPI grew at a faster pace than the all-item CPI, with food prices rising by 19% over the period and all-items CPI excluding food rising by 10.7% (Rollin, 2013). Canadian households that allocate a greater proportion of their budgets to food are most vulnerable to inflation in food prices. These groups include low-income households, households headed by seniors with fixed incomes and households in remote areas. Nationally, one in eight Canadian households experienced some level of food insecurity in 2011, as measured by an inability to access adequate food due to financial constraints (Tarasuk et al., 2011).

Food prices in local markets show year to year variability, so it is important to consider the interplay among macro-level factors, such as climate-related shocks to global food supplies, alongside sectoral and local-level factors in projecting future changes in food prices and in understanding the role of climate change in these shifts. For the past 10 years, researchers from Dalhousie University and the University of Guelph have produced a report forecasting potential price changes in eight food categories ("Canada's Food Price Report"). In recent years, this research has included a qualitative risk assessment of twelve supply and demand-side variables and their influence on Canadian food prices (*see* Table 9.9). Geopolitical risks, actions of the food processing industry and consumer purchasing power were the top risks in 2019, 2020 and 2021 forecasts at the macro, sectoral and domestic level, respectively.

Table 9.9: A range of macro (global), sectoral and domestic factors shape food prices Canadians see in local markets

LEVEL	FACTOR	2019		2020	
		IMPACT	LIKELIHOOD	IMPACT	LIKELIHOOD
Macro-level	Climate change (~)	4	4	5	5
	Geopolitical risks (~)	5	5	5	5
	Input costs (+)	4	4	4	4
	Energy costs (*)	3	4	3	4
	Inflation (+)	4	5	3	4

LEVEL	FACTOR	2019		2020	
		IMPACT	LIKELIHOOD	IMPACT	LIKELIHOOD
Macro-level (continued)	Currencies and trade environment (~)	4	5	4	5
Sectoral-level	Food retail and distribution landscape (-)	5	4	4	4
	Food processing industry (+)	4	5	5	4
	Policy context (-)	5	5	3	5
	Consumer food awareness and trends (-)	4	5	3	4
Domestic-level	Consumer indebtedness (-)	4	5	5	5
	Consumer income and income distribution (-)	4	5	5	5

Note: This table provides a qualitative forecast of each of these factors for 2019, 2020 and 2021 along two dimensions: likelihood of occurrence and impact on food prices should it occur. Likelihood is represented on a 5-point scale, with 4 representing "likely" and 5 "very likely." Impact is represented on a 5-point scale, with 3 representing "moderate," 4 "significant" and 5 "very significant." Factors can affect prices in several ways: they can exert downward (-) or upward (+) pressure on prices, or their effect can be variable (~) or negligible (*).

Source: Authors' elaboration, based on Dalhousie University and University of Guelph, 2019, 2020, 2021.

Agriculture and food products are particularly climate-sensitive and heavily traded (Dellink et al., 2017), consequently, the nexus of international trade, climate change and food security is receiving international attention (Mbow et al., 2019; Food and Agriculture Organization, 2018; Mosnier et al., 2014). Studies project a drop in global agricultural production, an increase in world food prices, increased bilateral food trade activity and a loss in economic welfare resulting from climate change by the 2050s and 2080s (*see* Table 9.10; Food and Agriculture Organization, 2018). Another common thread is the uneven impact among global regions, with food-importing tropical countries particularly vulnerable to climate change because of high economic sensitivity to yield and terms-of-trade shocks and high exposure to climate hazards (Gouel and Laborde, 2018; Distefano et al., 2017). In contrast to global projections, these same studies show positive outcomes for Canada for some indicators, including an increase in agricultural wages and in economic welfare. However, evaluating the bottom line on food security is subject to several sources of uncertainty, including: the magnitude of climate change and its diverse local impacts; the climate hazards considered; the future productivity and nutritional value assumed for a range of agricultural staples and food items; the interactive effects between climate change, domestic production and imports; adaptation by producers and consumers; and the responsiveness of trade to price signals. For example, one study modelling climate change impacts on global markets for 18 crops to 2050 suggests a change in crop calories available for Canadian consumers of between -15% to +4% relative to a pre-climate change baseline (Mosnier et al., 2014), which reflects uncertainty in the direction as well as the magnitude of change.

Table 9.10: Summary of selected international studies of climate change impacts on agriculture and trade

STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES	
			GLOBAL	*CANADA*
Costinot et al. (2014)	Climate-driven agronomic changes for 10 crops by the 2080s under a high (IPCC SRES A1F1) global emissions scenario, allowing for plant carbon dioxide fertilization Three counterfactual scenarios: full adjustment, no production adjustment (countries free to trade) and no trade adjustment (farmers can adjust operations)	Impacts on agricultural productivity for 10 major crops (banana, corn, cotton, oil palm, rice, soybean, sugarcane, tomato, wheat, white potato) across 50 countries Welfare changes as a % of GDP relative to “pre-climate change” baseline (using a computable general equilibrium, or CGE, model)	Welfare change as a % of total GDP in the 2080s of -0.26% (full adjustment); -0.78% (no production adjustment); -0.27% (no trade adjustment)	Welfare change as a % of total GDP in the 2080s of +0.59% (full adjustment); +0.47% (no production adjustment); +0.63% (no trade adjustment)

STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES	
			GLOBAL	*CANADA*
Mosnier et al. (2014)	Climate-driven agronomic changes for 18 crops by the 2050s under a high global emissions scenario (IPCC SRES A2) and 3 global climate models (GCMs) Assume growth in calorie demand driven by population and economic growth. Counterfactual scenarios allow for adjustments in production, management, trade and consumption	Impacts on crop yield for 18 major crops (barley, cassava, chickpeas, corn, cotton, dry beans, groundnut, millet, oil palm, potato, rapeseed, rice, sorghum, soybeans, sugarcane, sunflower, sweet potato, wheat) Changes in crop calorie availability for food consumption relative to "pre-climate change" baseline using the GLOBIOM partial equilibrium model	Change in global crop calorie availability in the 2050s between +2% and -3% depending on the GCM	Change in crop calorie availability in the 2050s between -15% to +4% Change in domestic production (tons) in the 2050s between -18% to +5% Change in total imports (tons) in the 2050s between -8% to 0%

STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES	
			GLOBAL	*CANADA*
Cui et al. (2018)	Climate-driven changes in yield of all major food and agricultural commodities by 2050 under a moderate emissions scenario (IPCC RCP6.0) Counterfactual baseline scenario assumes GDP, population and crop yields due to technological change grow by 134.7%, 38.7% and 38%, respectively, from 2011 to 2050. Counterfactual trade liberalization scenario removes all import tariffs and export taxes/subsidies for agricultural and food	Impacts on yields of major crop, livestock and processed foods Changes in 1) GDP, 2) food and agricultural trade and 3) agricultural worker wages relative to the baseline at 2050 (using a CGE model)	Change in global GDP in the climate change scenario in 2050 relative to baseline is -0.18% Change in global GDP in the climate change + trade liberalization scenario in 2050 relative to baseline is -0.17% Change in global food and agricultural net exports (billion US$2011) under climate change + trade liberalization in 2050 relative to baseline is +$62 billion, balanced by the same amount of increase in net food imports by net food importing regions Change in global agricultural wage in the climate change scenario in 2050 relative to baseline is -0.24%	Change in GDP in the climate change scenario in 2050 relative to baseline is +0.12% Change in food and agricultural net exports (US$2011) under climate change + trade liberalization in 2050 relative to baseline is -$1 billion Change in agricultural wage in the climate change scenario in 2050 relative to baseline is +8.0%

STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES	
			GLOBAL	*CANADA*
Gouel and Laborde (2018)	Climate-driven changes in yield of 35 crops, livestock and other commodities by the 2080s under a high emissions scenario (IPCC SRES A1F1) Counterfactual scenarios include no adjustments in production and trade-restriction assumptions	Impacts on agricultural productivity for 35 crops across 50 countries Welfare changes as a % of GDP relative to "pre-climate change" baseline (using a CGE model)	Welfare change as a % of total GDP in the 2080s of -1.72% relative to pre-climate change baseline Welfare change as a % of total GDP in the 2080s (relative to climate change scenario) from limits to production adjustments is -3.71%; from limits to bilateral import shares is -e3.02%; from limits to export shares is -2.18%	Welfare change as a % of GDP in the 2080s of +2.36% (agriculture terms of trade) and +0.49% (productivity change), relative to pre-climate change baseline Welfare change as a % of GDP in the 2080s (relative to climate change scenario) from limits to production adjustments is +6.92%; from limits to bilateral import shares is -0.28%; from limits to export shares is +3.65%

There are few studies that evaluate future climate change impacts and patterns of international trade (Dawson et al., 2020b), with results for Canada available in a limited number of them (*see* Table 9.11). Studies employ economic simulation models and introduce climate change impacts—also referred to as damages—as external shocks to subnational, national and regional economies, examining interactions across sectors, geographies, producers, consumers, as well as economy-wide phenomena (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter for key definitions). Comparing results across studies is difficult due to differences in scope (temporal and spatial), coverage (climate change impact categories, goods and sectors), baselines, scenarios (climate, socioeconomic and policy) and simplified assumptions about economic systems, among other factors. Even studies focused on a single sector can generate wide-ranging projections, since there can be differences in model structures (e.g., single sector versus whole economy, regions represented), trade specifications, goods included, price and consumption sensitivities (Food and Agriculture Organization, 2018). Canadian studies assessing the economic impacts of climate change on forestry alone and in combination with impacts on agricultural land services illustrate the importance of multi-regional and multi-sectoral modelling in improving the accuracy of analysis (Ochuodho et al., 2016; Ochuodho and Lantz, 2014).

Table 9.11: Summary of select international studies on the economic consequences of climate change impacts on international trade

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES		
			GLOBAL	*CANADA OR NORTH AMERICA*	*UNITED STATES*
Transport (global) Chatzivasileiadis et al. (2016)	Climate-driven sea-level rise (SLR) by 2050 under a high emissions scenario (RCP8.5) "Middle of the road" shared socioeconomic development pathway (IPCC SSP2) and three scenarios of SLR-induced transport disruption	Coastal land and capital losses due to submergence and sea-flood damage as well as SLR-induced transportation disruptions Direct and indirect economic effects (changes in production technologies, consumption patterns and international trade patterns), including changes in trade activity, terms of trade and welfare relative to "no-climate change" (using a CGE model)	% change in global exports in 2050 across three scenarios is 0.51% (0.44% to 0.61%) Change in global terms of trade (US$) in 2050 across three scenarios is -$7 million (-$4.3 to -$11.4 million) Global welfare change (US$) in 2050 across three scenarios is $50 billion (-$42 to $61 billion)	% change in North American exports in 2050 across three scenarios is 0.49% (0.39% to 0.53%) Change in terms of trade (US$) in 2050 for North America across three scenarios is +$535 million ($380 to $630 million) Welfare change (US$) in 2050 for North America across three scenarios is -$9.7 billion (-$7.8 billion to -$12.4 billion)	

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES		
			GLOBAL	*CANADA OR NORTH AMERICA*	*UNITED STATES*
Multi-sector (global) OECD (2015)	Average global temperature change of 2.5˚C (likely range of 1.6˚C to 3.6˚C) above pre-industrial levels by 2060 “No damage” baseline includes annual average growth in GDP. Market-driven adaptation measures are considered	Impact on crop yields and fish catches; coastal zones; human health; labour productivity; energy demand; tourism flows and damages from hurricanes Direct and indirect economic effects, including % change in GDP relative to “no-damage” baseline by 2060 from all impact categories and from agriculture impacts alone (using a CGE model)	% change in global GDP by 2060 from all impact categories of -1.52% % change in global GDP by 2060 from climate impacts on agriculture of -0.48%	% change in Canadian GDP by 2060 from all impact categories of +0.88% % change in Canadian GDP from climate impacts on agriculture of -0.11%	% change in US GDP by 2060 from all impact categories of -0.47% % change in US GDP by 2060 from climate impacts on agriculture of -0.27%

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES		
			GLOBAL	*CANADA OR NORTH AMERICA*	*UNITED STATES*
Multi-sector (global) Dellink et al. (2017)	Average global temperature change of 2.5˚C (likely range of 1.6˚C to 3.6˚C) above pre-industrial levels by 2060 “No damage” baseline includes annual average growth in GDP. Market-driven adaptation measures are considered	Impact on crop yields and fish catches; coastal zones; human health; labour productivity; energy demand; tourism flows and damages from hurricanes Direct and indirect economic effects, including % change in trade volumes relative to “no-damage” baseline by 2060 from all impact categories and from changes in revealed comparative advantage from climate change impacts on agriculture (using a CGE model)	% change in global trade volumes in 2060 compared to “no damage” baseline is -1.8% (exports) and -1.6% (imports)	% change in trade volumes in 2060 compared to “no damage” baseline of +0.2% (exports) and +0.1% (imports) % change in revealed comparative advantage levels for food products at 2060 relative to “no damage” baseline of +0.2%	% change in trade volumes in 2060 compared to “no damage” baseline of -0.5% (exports) and -1% (imports) % change in revealed comparative advantage levels for food products at 2060 relative to “no damage” baseline for the US is +0.6%

SECTOR AND STUDY	CLIMATE AND SOCIOECONOMIC SCENARIOS	PHYSICAL AND ECONOMIC IMPACTS	TRADE-RELATED CONSEQUENCES		
			GLOBAL	*CANADA OR NORTH AMERICA*	*UNITED STATES*
Multi-sector (United States) Zhang et al. (2018)	Annual mean temperature rise in the US on a decadal basis from 2020 to 2100 under a moderate emissions scenario (RCP4.5) Population and economies fixed at 2012 values, (reference year)	Impact on agricultural yield, energy demand and labour in the US Economic ripple effects on the rest of the world from direct economic damage and indirect economic impact of climate change in the US (using an International Ripple Effect Input-Output model)	Economic ripple effects on the world in 2050 (annual mean temperature rise of 1.51°C compared to 2012) are 51.5% of the direct economic damage in the United States	% change in Canadian GDP by 2050 from the economic ripple effects of climate change impacts in the US of -0.4% (-0.1% to -0.6%) % change in Canadian sectoral GDP by 2050 from the economic ripple effects of climate change impacts in the US of -0.16% (mining); -0.12% ("other services"), -0.10% (manufacturing)	

Because studies are limited and their methods inconsistent, confidence in numerical results is low. However, there are some qualitative findings on climate change and trade that are noteworthy. Studies show that Canada is among the few global regions with the potential to experience positive GDP impacts, gains in terms of trade and a rise in exports by mid-century from climate-induced changes across multiple sectors (Dellink et al., 2017; Chatzivasileiadis et al., 2016; OECD, 2015). Relative to other parts of the world, Canada's macro-economy may not be as affected by climate change impacts due to gains (or relatively fewer losses) in competitiveness in domestic and international markets (Dellink et al., 2017). Economic benefits to Canada relate to increased demand for energy, health services and tourism (OECD, 2015). Trade links between different regions can propagate or attenuate risk, so a closer look at the climate sensitivity of major trading nations is warranted (Kovacs and Thistlethwaite, 2014). One study modelled the global economic consequences of climate change impacts on crop yields, energy demand and labour productivity in the United States to 2100, under a range of temperature-rise scenarios (Zhang et al., 2018). The economic ripple effects globally are a sizeable portion of direct damages in the United States and are greater for Canada than for other regions modelled, including negative economy-wide and sectoral impacts (e.g., on mining, manufacturing and "other services", in particular) (Zhang et al., 2018). Similarly, researchers in Europe have modelled the trade-related effects of climate change impacts occurring outside of the region, showing that the worst effects on welfare in the EU stem from impacts in either the Americas or Asia (Szewczyk et al., 2013). These types of analyses can help provide a more balanced view on the potential distribution of trade-related impacts of climate change in colder versus warmer regions of the world.

9.4.3 Adaptation

Climate change adaptation in international trade occurs at multiple scales. This includes actions by industry and economic actors to manage climate-induced disruptions to trade and take advantage of emerging markets for adaptation goods and services. It also includes spontaneous (i.e., market-driven) and planned actions to build climate resilience into global trade systems.

Canadian industry recognizes the relationship between climate policy and international competitiveness (Canadian Chamber of Commerce, 2019), but there is little evidence of action to assess and manage trade-related impacts from extreme events and climate variation (Kovacs and Thistlethwaite, 2014). In 2016, the Canadian Chamber of Commerce included climate change among the top ten barriers to competitiveness, pointing to the need for a national adaptation strategy (Canadian Chamber of Commerce, 2016). Its 2019 recommendation report on climate policy acknowledges the role of trade in Canada's low-carbon transition, but does not discuss adaptation (Canadian Chamber of Commerce, 2019). The Canadian Federation of Agriculture (2017) advocates for tools and financial incentives aimed at supporting adaptation planning by Canadian producers to protect farmers' livelihoods domestically, and to improve food security and the stability of global prices for staples in the event of crop failures in other producing regions. Despite some recognition of these indirect impacts of climate change as a business issue to be managed, evidence of the extent of business action to adapt to related risks and opportunities is patchy. Responses to a voluntary disclosure initiative in 2015 concluded that, in comparison with companies in 10 other countries, Canadian publicly listed companies underperformed in water risk assessment, a critical aspect of supply chain resilience (CDP, 2015). Conversely, case study research highlights some Canadian leadership in identifying and acting on climate change risk from overseas assets, suppliers and distribution networks (CPA Canada, 2015). Strategies to manage supply chains risks resulting from climate change include understanding how risks from climate impacts interact with other risks, using scenario planning to inform risk management plans and building partnerships to support sustainable sourcing of inputs in the event of resource scarcity (Das and Lashkari, 2015; Gledhill et al., n.d.). In managing supply chain risks, adaptation by port and terminal planners and operators is key to enhancing climate resilience of critical trade infrastructure, but incentives to take action are not always aligned (Ng et al., 2016). Since ports provide benefits at a range of scales, it is not always clear who should take the lead and how adaptive measures, including changes in technology, engineering, design and maintenance and insurance (Scott et al., 2013), should be financed (Becker et al., 2017). Experience with the Port of Vancouver—Canada's largest port in terms of tonnage—illustrates the gap that exists between adaptation planning and implementation (Becker et al., 2017). The Port Authority's strategy has centred on understanding and responding to coastal hazards, with a commitment to monitoring the effects of climate change and taking action, where necessary (Port of Vancouver, n.d.).

Adaptation involves taking advantage of potential opportunities resulting from climate change, such as the business and employment opportunities created by enhanced trade in climate change adaptation solutions (Trabacchi et al., 2020; Conference Board of Canada, 2017). As measured by the thematic focus of Nationally Determined Contributions submitted to the UN Framework Convention on Climate Change, countries in Latin America and the Caribbean, Africa and South Asia regard adaptation as a core development priority (Trabacchi et al., 2020). Countries that invest in building climate resilience and enabling growth in adaptation markets domestically could be at an advantage as global suppliers of adaptation solutions (Deloitte and ESSA Technologies Ltd., 2016). At a minimum, firms demonstrating international leadership in key areas of climate finance (i.e., funds given by industrialized countries to emerging economies), such as agriculture, engineering and construction, water and wastewater solutions, geomatics, professional consulting services, and information and communication technologies could benefit from the estimated US$60 billion to US$100 billion per year in global finance needed for adaptation in developing countries to 2050 (IPCC, 2014). Canada's expertise in forestry and forest products, engineering and coastal infrastructure, ocean technologies, water and wastewater and financial risk-transfer tools, among other sectors, could be harnessed to meet the growing global demand (Deloitte and ESSA Technologies Ltd., 2016; Kovacs and Thistlethwaite, 2014). Since 2018, Global Affairs Canada has increased support to Canadian firms' participation in emerging adaptation markets, including establishing a global network of Canadian trade commissioners dedicated to this task and providing market intelligence.

Short and long-term adjustments in trade in response to climate variability or extreme weather are essentially examples of adaptation, driven by market signals, and so enhancing trade activity could play a role in alleviating the future consequences of climate change. Imports and switches in suppliers can reduce pressure from year-to-year shocks in production and higher prices (Dellink et al., 2017; Baldos and Hertel, 2015; Mosnier et al., 2014; Stephan and Schenker, 2012). In the long term, production can shift to areas that have the comparative advantage of climate resilience (Baldos and Hertel, 2015; Stephan and Schenker, 2012). For example, a longer growing season in Canada and proactive adaptation by domestic producers could lead to agricultural surpluses, soil and water permitting, which could offset production shortfalls in other areas. Historical trade patterns illustrate the feasibility of relying on well-functioning trade as insurance against climate change risk. Demand-driven shocks to the forest sector over the past century that were transmitted through trade led to management responses of the scope and scale envisioned for climate change adaptation (Sohngen and Tian, 2016). Conversely, tariff and non-tariff barriers (e.g., export bans) to trade have hindered historical adjustments in global food trade in response to economic shocks (Baldos and Hertel, 2015). Studies modelling the future economic impact of climate change on global food and agriculture show a potential moderating effect of trade liberalization on climate-induced global food insecurity and production decline (Cui et al., 2018; Gouel and Laborde, 2018), as well as the important role of farmer-level adaptation in reducing economic loss (Costinot et al., 2014). These economic and modelling studies suggest that wealthier countries are more likely to capture gains from the adaptive effect of trade than are regions in the Global South, which sometimes lack resources and infrastructure for spontaneous adaptation. Financial support for planned adaptation, including through international assistance (*see* Section 9.6), could thus be justified on grounds of economic self-interest, alongside fairness and equity (Stephan and Schenker, 2012). Stylized representations of the evolution of international trade under climate change can fail to account for dynamics such as planned investment in trade infrastructure and removal of trade policies causing market distortions (e.g., subsidies) (Gouel and Laborde, 2018). Adaptation in this context involves, for example, promoting growth in sectors and regions to counteract scarcity in other countries as a result of climate change impacts, reducing import dependency for staples, diversifying trade partners and addressing weaknesses in trade institutions (Dallman, 2019; Mbow et al., 2019; Gouel and Laborde, 2018; Kovacs and Thistlethwaite, 2014).

9.5 Climate-related human migration and displacement will increase demands for immigration to Canada

Tropical cyclones, floods, droughts, wildfires and food insecurity displace millions of people each year. Climate change will generate growing numbers of migrants by mid- to late century, especially in Least Developed Countries in sub-Saharan Africa, Asia, and Latin America and the Caribbean. Canada will come under growing internal and external pressure to accept larger numbers of migrants from climate-disrupted regions.

Human migration and displacement can occur as a direct result of extreme weather and climate events, such as tropical cyclones, floods, droughts and wildfires, or as an indirect result of climate impacts on food supplies, freshwater availability and livelihoods. Migration responses to climatic risks are mediated by societal factors that affect adaptive capacity and by household characteristics. Globally, an average of 21 million people are displaced each year by floods, drought, storms, wildfire, extreme heat and other weather-related hazards. Climate change will exacerbate the frequency and severity of these events in many regions, and have particularly strong impacts on migration and displacement in Least Developed Countries in sub-Saharan Africa, South and Southeast Asia, Latin America and the Caribbean. Recent studies project a 50% increase in displacement risks with each additional degree Celsius of warming. Sea-level rise is already necessitating the relocation of small coastal communities in Alaska, Chesapeake Bay, the Gulf of Mexico, Fiji and Papua New Guinea. By 2100, rising seas will force the relocation of tens of millions of people living in coastal plains, river deltas and small island states, particularly in the Global South. Poverty and weak governance and institutions are root causes of large-scale or sudden displacements. As climate change intensifies, Canada can expect increased future demand for immigration from current source countries that are highly exposed to climate risks, such as the Philippines, China, India, Pakistan and Syria. The international community may also increasingly look to Canada to provide financial assistance and serve as a resettlement destination for people from highly vulnerable developing countries with historically few ties to Canada. Many heavily-populated coastal areas of the United States are highly exposed to extreme storms and floods, which will be amplified by rising sea levels. Most of those displaced will likely resettle within the U.S., but the scale of potential social and economic disruption that ensue merit monitoring for potential effects on established migrant networks to Canada.

9.5.1 Introduction

This section describes the relationship between climate change and human migration, discusses current and future estimates and trends of global climate-related migration, and outlines specific future concerns for Canada.

9.5.2 The climate-migration nexus

Migration movements are the cumulative result of cultural, economic, political, social and environmental drivers that operate at local to global scales (van Hear et al., 2018; Foresight, 2011). Links between climate change and migration are context specific and not always obvious, often because climate stressors alone rarely determine decisions to migrate (McLeman, 2014). Climatic events may directly stimulate displacement and migration, such as from New Orleans following Hurricane Katrina (DeWaard et al., 2016), or have an indirect influence, such as through climate-related shocks to food production or prices (Maharatna, 2014). International migrants may not disclose environmental motivations to officials, as receiving countries typically do not consider these as valid reasons for moving (for examples from Canada, *see* McLeman et al., 2017; Mezdour et al., 2015; Veronis and McLeman, 2014).

Current research identifies three sets of links between climate change and migration:

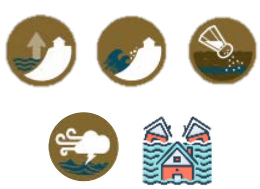
- Migration as household-level adaptation to climate risks (referred to hereafter as "adaptive migration");
- Displacement or planned relocation of people from areas impacted by, or highly exposed to, climate risk; and
- Immobility, or the inability to migrate, that traps people in highly exposed locations.

Adaptive migration ranges from temporary or seasonal moves to indefinite relocation; it can be a response to adverse climate events or an effort to take advantage of beneficial climate conditions. The most common adverse climate events associated with migration and displacement are extreme storms, floods and droughts (IDMC, 2020). Climate change can influence local, regional and international migration in multiple ways, depending on the specific impacts of climatic events and the mediating effects of societal and household characteristics (*see* Table 9.12). These can include changes in migration destinations, duration or timing, direction of net migration flows and migration participation rates (*see* Table 9.12; Suckall et al., 2017; Gray and Wise, 2016; McLeman, 2014; Black et al 2011).

Migration responses vary by the type of climate event and its characteristics, such as the rate of onset, duration and nature of the damage that it causes to infrastructure, property and households' livelihood assets (*see* Table 9.12). For example, tropical cyclones present three hazards at once: high winds that bring down trees and power lines, heavy rains that trigger flash floods and landslides, and storm surges that inundate low-lying areas. Such events generate short-term evacuations from affected communities; residents' likelihood to return, rebuild and stay depends on the extent of damage to homes and infrastructure and the ability of governments to assist in reconstruction (Fussell, 2018; Mallick and Vogt, 2012). In the weeks and months following the storm, out-migration from the affected area can increase as young workers seek wages to send home and assist in rebuilding homes and livelihoods (Loebach, 2016). This occurred, for example, in the surge of Puerto Rican workers who moved to the U.S. mainland in the wake of Hurricane Maria (Echenique and Melgar, 2018). In contrast, a slow-onset hazard, such as drought, may not stimulate migration immediately. A lag occurs as households seek to adapt through other, less disruptive means, with migration ensuing only as drought conditions persist and other adaptation options falter (Nawrotzki and DeWaard, 2016). Because homes or property tend to be intact, some household members can stay behind while, commonly, young adults migrate in search of work (Baez et al., 2017).

Table 9.12: Summary of key climatic drivers of migration, societal and household factors that mediate migration and potential outcomes of interactions

CLIMATE CHANGE STRESSOR	SOCIETAL-LEVEL MEDIATING FACTORS	HOUSEHOLD-LEVEL MEDIATING FACTORS	POTENTIAL MIGRATION OUTCOMES FROM INTERACTIONS OF FACTORS LISTED IN THE OTHER COLUMNS
Changes in the frequency, severity and/ or spatial extent of:  Changes to the following, associated with the above stressors: 	**Environmental** • Physical setting (e.g., tropical, temperate, sub-Arctic, coastal versus inland) • Topography, watershed characteristics, groundwater resources • Land cover • Baseline environmental damage (or remediation) from human activity	**Pre-existing characteristics** • Composition (e.g., family structure, number of members, ages, sex, dependents) • Human capital (e.g., education, employment skills, health) • Financial capital (e.g., direct & indirect sources of income, access to remittances, asset ownership) • Social capital (e.g. kinship ties, extended family networks, membership in formal and informal community organizations)	**Migration destinations** • Choice between short-distance destination over long-distance destinations • Choice of common destinations or new destinations **Migration duration or timing** • Temporary or seasonal versus indefinite migration • Unplanned migration, deferral of planned migration

CLIMATE CHANGE STRESSOR	SOCIETAL-LEVEL MEDIATING FACTORS	HOUSEHOLD-LEVEL MEDIATING FACTORS	POTENTIAL MIGRATION OUTCOMES FROM INTERACTIONS OF FACTORS LISTED IN THE OTHER COLUMNS
(continued from previous page)	**Economic** • Structure of the economy • Robustness of economic sectors and labour markets • Economic (in)equality and wealth distribution • Land tenure regimes	**Nature of impacts of specific climate-related events** • Injury or loss of life among household members • Damage to/loss of home • Loss of income, livelihood opportunities, assets • Losses experienced by neighbours, extended family members or local community • Temporary versus indefinite impacts	**Direction of net migration flows** • Rates of migration to specific locations may rise or fall • Source locales becoming destinations and vice versa • Climate event stimulating return migration to assist with recovery
Risks related to sea-level rise 	**Political** • Financial capacity of government • Government activity and effectiveness • Political stability, unrest or conflict • Corruption • Border controls and immigration regimes of neighbouring states		**Migration participation rates** • Rates of migration to specific locations may rise or fall • Migration rates of particular groups may change relative to others

CLIMATE CHANGE STRESSOR	SOCIETAL-LEVEL MEDIATING FACTORS	HOUSEHOLD-LEVEL MEDIATING FACTORS	POTENTIAL MIGRATION OUTCOMES FROM INTERACTIONS OF FACTORS LISTED IN THE OTHER COLUMNS
(continued from previous page)	**Social** • Demographic structure and population trends • Urbanization • Cultural norms about mobility and migration • Gender norms • Treatment of Indigenous groups, minorities and marginalized populations • Social networks and linguistic/cultural ties (domestic and foreign)	**Migration readiness** • Past migration experience • Transferability of job skills • Geographical extent of social networks • Ability of household to endure prolonged absence of individual members • Ability to finance migration	**Organized relocations and planned retreats** • Institutions actively assist the movement of individual households or communities **Immobility** • Relocating is the preferred response but is not feasible for households, resources are not forthcoming from institutions • Strong resistance to relocation may arise from cultural/social connections to place and/or indigeneity

Key

Enhanced erosion	Extreme heat	Extreme storms and related flooding
Floods	Food scarcity	Salinization of groundwater, soil
Droughts	Water scarcity	Inundation of low-lying coastal areas
Wildfires		Enhanced storm surges

Sources: McLeman, 2020; Hauer et al., 2020; Cattaneo et al., 2019; Baez et al., 2017; Suckall et al., 2017; Adams, 2016; Gray and Wise, 2016; Hunter et al., 2015; McLeman, 2014; Black et al., 2011.

Aside from the characteristics of the climate event, the propensity of people to migrate is also a function of the adaptation options available to affected households (Black et al., 2011). Household options are influenced by a wide range of economic, social, political and cultural processes that operate beyond the control or influence of the household, such as labour markets, government programs and safety nets, health care accessibility and insurance regimes, to name a few (*see* Table 9.12). Characteristics of households and their members, such as age, health, education, job skills, gender and extended family networks, also influence choices between *in situ* adaptation and migration by some or all household members (*see* Table 9.12).

9.5.3 Current and estimated climate-related migration

Estimates of global numbers of people displaced or who have migrated for climate-related reasons carry significant uncertainty. Global migration data are coarse, and attributing causality within these datasets is problematic. Most migration, whether for climatic or other reasons, is internal (within countries), flowing from rural to urban areas (Samers, 2010). Estimates of international migration produced by the Population Division of the UN's Department of Economic and Social Affairs are the accepted standard, registering 258 million international migrants worldwide in 2017 (UN Department of Economic and Social Affairs, 2017). These estimates are conservative and likely underestimate actual levels since they do not, for example, consider return migration (Azose and Raftery, 2019).

The most reliable data on climate-related migration are annual estimates by the International Disaster Monitoring Centre (IDMC) of the number of people that are internally displaced by disasters from natural hazards. These data include both temporarily and indefinitely displaced people, as well as climate and non-climate hazards. Since the IMDC began publishing annual statistics in 2008, an average of 21 million people have been displaced annually due to weather-related disasters.[1] The largest weather-related displacements occurred in India, the Philippines, Bangladesh, China, and the United States, with storms (13 million people worldwide in 2019) and floods (10 million people worldwide in 2019) as the main causes. IDMC statistics underestimate global environmental migration flows as they primarily record people who are involuntarily displaced within their home country by large disaster events, and do not count: 1) those displaced by smaller or ongoing events; 2) people who move for adaptive reasons beyond the confines of a disaster; or 3) international migrants.

Climate-related migration and displacement is commonly seen among subsistence agricultural populations, pastoralists and other groups that pursue resource-based livelihoods (e.g., fishers) in Least Developed Countries (LDCs), and may take the form of temporary, seasonal and longer-term migration (Afifi et al., 2016; Gautier et al., 2016; Gray and Wise, 2016). Many LDCs already have high rural–urban migration rates for social and economic reasons; extreme climate events and conditions amplify these already high rates, placing great strain on city services (Ishtiaque and Nazem, 2017). This in turn can reduce the quality of life and human security in cities and can lead urban professionals to pursue migration abroad, as has been observed within the movement of skilled worker migrants to Canada from Bangladesh, Haiti and several West African countries

1 Visit http://www.internal-displacement.org/ for latest statistics; at time of writing this chapter, the most recent IDMC statistics available were for 2019.

(*see* Figure 9.11; McLeman et al., 2017; Mezdour et al., 2015; Veronis and McLeman, 2014). Such migration is to the benefit of the receiving country, but represents a loss of human capital for the sending community.

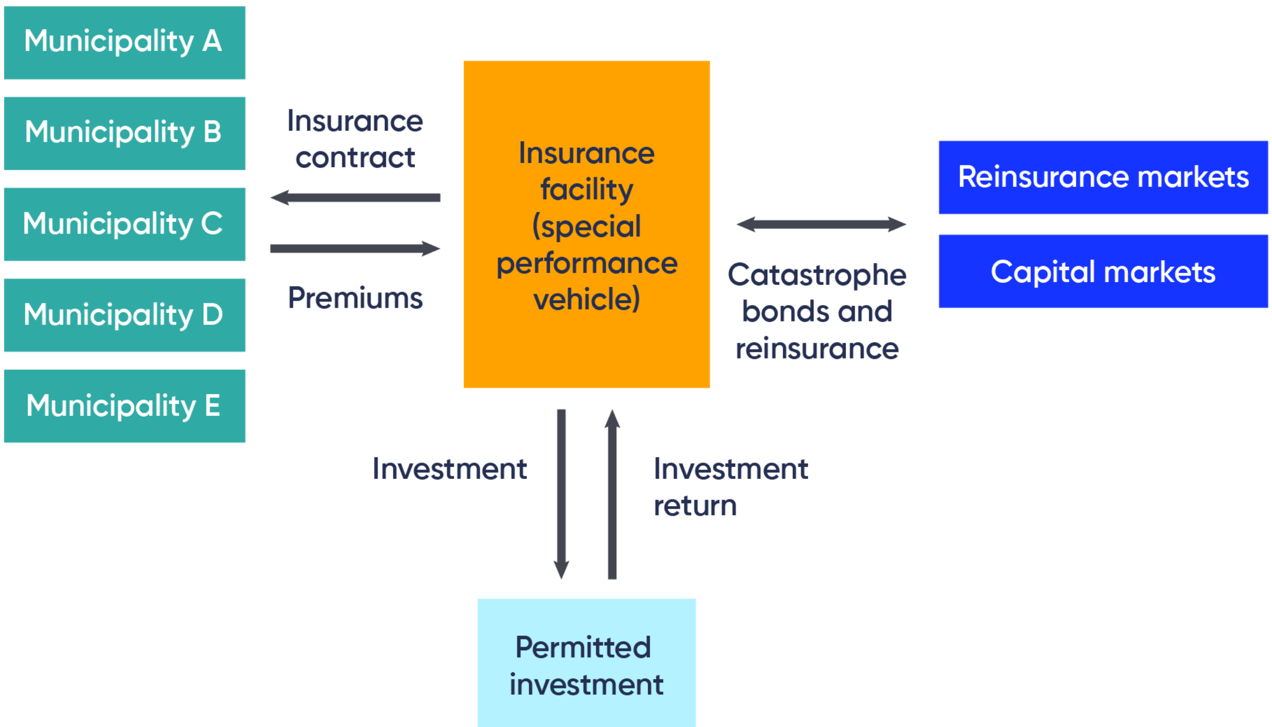


Figure 9.11: Cascading effects of environmentally induced rural to urban migration in Least Developed Countries. Source: Adapted from Veronis and McLeman, 2014.

Climate migration does not occur exclusively in LDCs. In the United States, Hurricane Katrina is the most infamous example, with the population of New Orleans being 40% smaller today than it was immediately before the storm (DeWaard et al., 2016). The U.S. federal government is actively relocating several Indigenous communities in Alaska situated in rapidly eroding locations (Marino and Lazrus, 2015), as well as the Mississippi delta community of Isle de Jean Charles, Louisiana. Such efforts are costly; the cost of the Isle de Jean Charles relocation, for example, is reaching US$43 million (Sack and Schwartz, 2018).

Future levels and patterns of climate migration are difficult to estimate as they depend on the combined effect of many factors (Beneviste et al., 2020; McLeman, 2019), chiefly:

- Future levels of GHG emissions and consequent impacts on temperatures and precipitation patterns;
- Future rates of change in frequency and severity of storms, floods, droughts;
- Future rates of relative sea-level rise;

- Future population growth levels in areas highly exposed to climate risks;
- Future socioeconomic growth, progress towards the UN Sustainable Development Goals and the success of adaptive capacity building in LDCs; and
- Future immigration and border control policies of developed countries.

A recent World Bank study (Rigaud et al., 2018) estimated that up to 143 million people could be displaced by the impacts of climate change in LDCs by mid-century in the absence of concerted actions to reduce global GHG emissions and to accelerate sustainable development. Combining flood displacement data from the IMDC with standardized scenarios for GHG emissions, socioeconomic development and population growth, it is estimated that each additional degree Celsius of warming increases global displacement risks by 50% (Kam et al., 2021). By the year 2060, it is estimated that one billion people will live in low-elevation coastal zones (LECZs)—areas less than 10 m above mean sea level—and thus be exposed to sea-level rise and accelerated coastal hazards (Neumann et al., 2015). The greatest proportion at risk lives in densely populated coastal deltas in Bangladesh, China, India, Indonesia and Vietnam, with coastal populations in Africa and the United States also growing rapidly (Merkens et al., 2016). For example, southeastern Florida's population is expected to grow to nearly 10 million by the year 2030 (Curtis and Schneider, 2011). A mean sea-level rise of 0.8 m by the end of this century would necessitate the relocation of up to 4.2 million people in the United States (Hauer et al., 2020, 2016). There is a pressing need for further research and modelling to generate statistical projections of future climate-related migration at global and regional scales under a range of climate and development scenarios (McLeman, 2019). Uncertainty in these projections is likely to remain high, making research on conditions that shape migration choices and on the effectiveness of adaptive strategies perhaps even more pressing (McMichael et al., 2020).

9.5.4 Future outlook for Canada

Canada is an attractive destination for international migration, and this will be magnified by adverse climate change impacts. Canada's immigration policies stand in growing contrast with recent trends in Australia, the European Union and the United States towards less liberal migration policies, greater levels of border enforcement and criminalization of unauthorized migration (de Haas et al., 2019; McLeman, 2019). These latter trends are at odds with international development needs in a climate-disrupted future. The 2018 *United Nations Global Compact for Safe, Orderly and Regular Migration*, to which Canada is a signatory, provides instructive policy guidance and objectives for ensuring that management of climate-related migration is done effectively, benefits sending and receiving areas, and protects the rights of migrants and their families (McLeman, 2019). Most international migration, including instances of climate-related migration, occurs between countries with contiguous borders (Stojanov et al., 2017; Hunter et al., 2013). Canada is anomalous in that five of its six largest immigration source countries are in Asia and the Middle East (India, the Philippines, China, Syria and Pakistan), with the United States representing the fourth-largest source of permanent migrants. Canada's largest source countries of international migrants are expected to experience increased risks of extreme weather events, droughts, water scarcity and sustained heat events by 2050 and beyond, and (with the exception of Syria) have large populations residing in low-lying coastal areas (IPCC, 2014).

Most people seeking to migrate to Canada for climate-related reasons are likely to be people with family or social connections in Canada that can facilitate their travel and settlement, and third-country nationals (most likely from Latin America and the Caribbean) that enter Canada from the United States, seeking admission as refugees or for humanitarian and compassionate reasons. For the latter group, the number of future arrivals will be heavily mediated by U.S. immigration and border policies (McLeman, 2019). Most future climate-related migration and displacement in the U.S. is likely to be internal, but the sheer scale of involuntary displacement under high emissions scenarios projected by Hauer et al. (2017) and socioeconomic disruptions that would ensue bear monitoring for potential effects on established migration flows between Canada and the U.S. Migrants with family connections are unlikely to place excessive demands on Canadian social services. The poorest, most vulnerable people in LDCs typically lack the financial wherewithal to undertake long-distance migration to Canada or other high-income countries and are more likely to be trapped in their home countries (Zickgraf, 2018; Black et al., 2011). International assistance to address the underlying causes of involuntary climate-related migration in the near term will help make LDCs more resilient in the long run and enhance their chances of meeting the Sustainable Development Goals (Rigaud et al, 2018). Global Affairs Canada projects that address water scarcity in rural Ethiopia are a practical example of future development programming of this type (Government of Canada, 2017a).

Canadian immigration and refugee programs currently do not take climate change into account when determining eligibility, and the *UN Convention Relating to the Status of Refugees* does not apply to people moving for climate-related reasons. Canada should expect increasing pressure in coming decades from the international community to accept the relocation of people displaced by climate change in countries that are not historically significant migration sources for Canada. Small Island States are obvious candidates, given the limited adaptation and internal relocation options that they have with respect to sea-level rise (Kelman, 2015). A petition made by a Kiribati family to the UN Human Rights Committee fighting deportation from New Zealand on the grounds that their home island was no longer viable due to rising sea levels, resulted in a decision that receiving countries should not repatriate people whose lives are threatened by climate change impacts (UN Human Rights Committee, 2020). Unlike New Zealand, Canada has yet to receive significant numbers of humanitarian or refugee claims for permanent residence, but this can be expected to change as the impacts of climate change become more pronounced in countries where political instability is ongoing (Veronis, 2014).

The potential association between adverse climate conditions, migration and occurrences of violence and conflict in LDCs is subject to active investigation (*see* Section 9.6.2). Climate-related violence between groups competing for resources may lead directly or indirectly to internal and international migration in affected regions (Abel et al., 2019). Climate-related migration can increase or alternatively decrease the risk of violence and conflict within LDCs, depending on local circumstances (Freeman, 2017), but there is no evidence that climate-related migration triggers conflict between states. Research from East Africa finds that climate migrants are more likely to be victims of violence than perpetrators (Linke et al., 2018). A recurrent conclusion in published research is that the relationship between climate change and conflict is not deterministic, with numerous points for intervention before violence emerges (Mach et al., 2019; Selby et al., 2017; Brzoska and Fröhlich, 2016; Burrows and Kinney 2016). The impacts of climate change in water-scarce and politically unstable LDCs in sub-Saharan Africa could conceivably generate future demands for international intervention (*see* Case Story 9.4).

Case Story 9.4: The role of climate change in conflict and migration in Mali

In August 2018, Canadian Armed Forces personnel were deployed to Mali to support the UN Multidimensional Integrated Stabilization Mission for a 12-month mission. Mali is a semi-arid sub-Saharan nation where agriculture is the principal livelihood base for the majority of the population. Environmental factors and conflicts over land use have been significant factors in the emergence and persistence of conflict in Mali. Severe droughts in the late 1980s triggered high levels of rural out-migration (Findley, 1994). Migration between rural and urban areas for socioeconomic reasons is common. However, adverse climate events have changed the patterns and duration of short-term population movements (Liehr et al., 2016). Drier conditions in a changing climate could depress crop yields and fodder for livestock (Butt et al., 2005).

Studies on the conflict in Mali conclude that climate events, such as drought, do not directly cause violence and conflict but can contribute to it. For example, in Mali's Mopti region, four factors led pastoralists to join militant jihadist groups that are challenging government authority (Benjaminsen and Ba, 2019; Benjaminsen et al; 2012; Benjaminsen, 2008):

- Droughts, which led to increased migration of young Tuareg men to Libya, where they were radicalized;
- Encroachment of crop farming on land traditionally used by pastoralists that constrained the mobility of people and livestock;
- A lack of sound governance structures and clear land tenure arrangements in rural areas; and
- Corruption and predatory rent-seeking in rural areas by government officials, often under the guise of measures to combat desertification.

Promoting better governance and adaptive capacity in rural areas is essential for the long-term success of international interventions in Mali. This includes land-tenure reforms that recognize rural small holders and programming that balances the interests of pastoralists with crop farmers. Emerging research on drought and food security in Mali identifies diversified livestock and crop farming as an important development pathway to increase the climate resilience of rural Malians (Giannini et al., 2017).

9.6 Increased demand for international assistance is expected

Climate change can undermine human security in developing countries and increase demands for Canadian international assistance. Canada is addressing climate risk to development and humanitarian goals by providing financial and technical assistance for adaptation and climate resilience.

Developing countries have less capacity to adapt and are therefore more vulnerable to the impacts of climate change than developed countries. Reasons for this include structural challenges that lead to political or economic marginalization, weakened institutions, environmental degradation, inadequacies in existing infrastructure and different abilities to pay for adaptation. Climate change can undermine human security and increase demands on international assistance. Climate change can also act as a multiplier of existing threats and pressures unrelated to climate, increasing exposure to harm, social unrest, and the removal of freedoms and capacities to live with dignity. Global stability and the welfare of citizens in countries abroad is a long-standing focus of Canadian foreign policy. As climate change impacts increase and intensify, Canada can expect increased future demand for international assistance, including responding to humanitarian crises, particularly in countries where Canada is already active. In anticipation of these pressures, Canada is working with developing-country partners to address the impacts of climate change through its international assistance activities. This includes helping to strengthen vulnerable nations' capacities to adapt to climate change through funding and programs that, among other outcomes, generate, increase access to, and facilitate the use of, knowledge, skills, infrastructure and technology needed to build climate resilience.

9.6.1 Introduction

Global stability and the welfare of citizens in countries abroad are tenets of Canadian foreign policy (Seyle, 2019; Bernard, 2006), as is accounting for local context in working with the international community to deliver stability and welfare (Government of Canada, 2017a, b). The impacts of climate change and variability are already affecting communities globally, particularly in the Least Developed Countries. This section examines the potential impacts of climate change on Canada's international assistance priorities. It describes the relationship between climate change and human security, discusses the implications of climate change on demands for international assistance and assesses evidence of Canada's responses to date.

9.6.2 The climate-security connection

Climate change will impact developing countries more than developed countries due to differences in vulnerability and capacities to adapt (Ahmadalipour et al., 2019; King and Harrington, 2018; Adger et al., 2014), in some cases resulting in human insecurity. Human security is "a condition that exists when the vital core of human lives is protected, and when people have the freedom and capacity to live with dignity" (Adger et al., 2014, p. 759). Human insecurity, therefore, encompasses threats to health and well-being, economic and political inclusion and threats to culture. The mechanisms by which climate change can lead to human insecurity in developing countries are an active area of study in Canada and globally (De Souza et al., 2015; Busby et al., 2014; Ericksen et al., 2011). These mechanisms relate to complex and multi-faceted trends affecting the capacity of countries to cope with shocks and to adapt in the long term, including, structural challenges that lead to political or economic marginalization, weakened institutions, environmental degradation, inadequacies in existing infrastructure, varying levels of wealth to offset the costs of adapting to climate impacts (Harrington et al., 2016), changing demographics (e.g., growing populations and increased rural-to-urban migration) and other important factors (e.g., prior conflict experience).

Research to evaluate the links between climate change and violent conflict in particular has improved over the past decades. Security experts generally agree that climate change is a "threat multiplier", exacerbating existing political instability and conflict, or potentially tipping stable countries into instability. Although the concept adds complexity to the task of understanding the specific relationships between climate change and conflict (Busby, 2020), linking environment and conflict without capturing the underlying mechanisms at play can lead to ineffective interventions. Research in the 1990s (Homer-Dixon, 1991) without this lens led some researchers and policymakers to assume scarcity directly led to conflict. Another research gap was the excessive reliance on a small number of case studies from sub-Saharan Africa and the Middle East, such as conflicts in Darfur and Syria, to generalize insights (Adams et al., 2018; Hendrix, 2018). A robust academic field has now developed, demonstrating that climate is related to armed conflict that takes place within countries, but is not the most significant driver of large-scale conflict (Mach et al., 2019; Hsiang and Burke, 2013). Research on the connection between climate and conflict increasingly focuses on the important roles of governance and institutions, adaptive capacity and cooperative behaviour (Koubi, 2019; Gilmore et al., 2018; Gilmore, 2017; Theisen, 2017; Buhaug, 2016; Buhaug, 2015; Rüttinger et al., 2015; Meierding, 2013; Gleditsch, 2012).

Current research efforts serve to move beyond the "threat multiplier" concept in order to identify context-specific interventions that can address climate-related risks of violent conflict (Busby, 2020). Based on expert elicitation research, recent work points to low socioeconomic development, diminished state capacity and intergroup inequality as factors relating climate with internal armed conflict (Mach et al., 2019). Others have found that countries with high rates of political exclusion and high dependence on agricultural labour are at risk of prolonged or worsened conflict and humanitarian emergencies when faced with climate-related hazards like severe droughts (Busby and von Uexkull, 2018). The need to consider local factors when assessing how climate change shapes conflict risk is key. For example, in sub-Saharan Africa, the impacts of drought on crop production and on the availability of water and forage for livestock have a weak association with outbreaks of violent conflicts, with intervening political and socioeconomic factors having a more direct influence (Ayana et al., 2016; Buhaug, 2015; Buhaug et al., 2014). Climate change mitigation efforts associated with land-use change can add to the potential for conflict (Froese and Schilling, 2019), which highlights the need for conflict sensitivity in designing initiatives to reduce GHGs or enhance carbon sinks.

The link between conflict and climate-related migration is being increasingly studied in an effort to understand this complex relationship (Boas et al., 2019; Brzoska and Fröhlich, 2016) and match humanitarian responses to needs (*see* Section 9.6). An example of where the conflict narrative has been studied and challenged among scholars relates to the contribution of water scarcity due to prolonged drought to the emergence of the Syrian civil conflict (Ide, 2018; Feitelson and Tubi, 2017; Selby et al., 2017; Kelley et al., 2015; Gleick, 2014). Statistical analysis of climatic and non-climatic factors in global patterns of conflict and asylum-seeking between 2006 and 2015 found that drought conditions were likely secondary in generating conflict and asylum-seeking outmigration from Syria in the years 2010 to 2012, with non-climatic factors playing the primary role (Abel et al., 2019). Extreme events and changing climate conditions interact with political, economic, social, cultural and other factors and can generate or exacerbate conflicts and forced migration, but a conflict and refugee crisis of the scale of Syria is not solely attributable to climate factors.

9.6.3 Demands on international assistance

Heightened demand for international assistance as a result of climate change is foreseeable—even if the causal pathways are complex. Climate change may lead to complex humanitarian crises through threats to food security, livelihoods, public health, mobility and geopolitical stability (Norwegian Red Cross, 2019). Beyond humanitarian assistance and development organizations, a number of national security and other international institutions note the potential for climate change to require additional international assistance, including the U.S. Department of Defense (U.S. Department of Defense, 2014), the United States Executive Office of the President (United States Exec. Order 14008, 2021) and intelligence community (Coats, 2019), think tanks (Guy et al., 2020), the United Nations Security Council (UN News, 2019) and the G7 (UNFCCC, 2015). Canada's Feminist International Assistance Policy draws attention to the destabilizing effects climate change can have on the poorest and most vulnerable communities (Government of Canada, 2017a). Similarly, Canada's Strong, Secure, Engaged defence policy recognizes the potential for climate change to exacerbate existing fragilities in some countries, increasing tensions and contributing to humanitarian crises (Government of Canada, 2017b).

Many developing countries have made significant progress on climate change adaptation and climate-related disaster risk reduction to date, with important lessons to be drawn for developed countries (*see* Case Story 9.5). Countries' progress in defining their adaptation priorities, establishing governance structures that facilitate adaptation efforts, implementing adaptation-focused projects and programs, and leveraging financing for priority adaptation efforts is highly variable (Parry and Terton, 2016). In some cases, community-level action is outpacing action at the national level, so care must be taken to avoid generalizing the climate resilience of developing countries based on their national efforts alone.

However, for many developing countries with lower income, including LDCs, building climate resilience and adapting to the impacts of climate change is unaffordable without assistance from developed countries as partners. Accurate and consistent assessments of the overall economic costs of climate change impacts on developing countries are a work in progress. Nevertheless, research and policy communities generally agree that the costs will be substantial. The World Bank and the UN Framework Convention on Climate Change (UNFCCC) have estimated adaptation investment needs in developing countries by 2030 in the range of US$60 to $100 billion per year (Fankhauser et al., 2016). In addition, there is growing recognition that climate change adaptation should be mainstreamed into regular international assistance efforts. There is also the potential for climate considerations to compete with investments for ongoing development priorities (e.g., healthcare, social welfare and education).

9.6.4 Canada's response and outlook

Canada's response to the increased threats posed by climate change to developing countries over the last decade has focused on contributing to global climate finance (*see* Box 9.3), supporting knowledge generation relevant for adaptation in developing countries and identifying priorities for action that address climate risks through international assistance activities. Canada's approach is continuing to evolve, as exemplified in the 2019 mandate of the Minister of National Defence, which made a commitment to draw on the expertise of the Canadian Armed Forces to help other countries at greater risk of disasters due to climate change (Trudeau, 2020). Because the lines between post-disaster humanitarian work and development interventions to reduce poverty are becoming increasingly blurred, improved collaboration between these two communities of practice could help address root causes of vulnerability and contribute to long-term adaptation (Marin and Naess, 2017).

Box 9.3: Climate finance

Climate finance refers to financial support for mitigation and/or adaptation actions that address climate change. It differs from official development assistance in that climate finance is intended to be additional to international development commitments. The Paris Agreement calls for financial assistance from Parties to the UNFCCC, with more financial resources to less wealthy and more vulnerable Parties. Climate finance is an important tool to help build the resilience of countries for which the costs of adaptation could be unaffordable. As a Party to the UNFCCC and the Paris Agreement, Canada has obligations to provide finance to developing countries to support their efforts to adapt to climate change.

Advocacy by governments and non-governmental organizations led developed countries to commit to raising US$100 billion annually by 2020 from public and private sources for climate finance in developing countries, but progress has been mixed in meeting that target (African Development Bank et al., 2019; OECD, 2019, 2018a-c, 2016). Progress has been made in total financing made available by developed countries in the years between 2013 and 2017 in increasing annual investments (up to US$71.2 billion annually from US$52.2 billion), but a significant skew remains towards GHG emissions reduction (73%) over adaptation funding (19%) as of 2017 (OECD, 2019).

More information is available on the UNFCCC's website at this link: https://unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance.

Canada's leadership on global climate finance has varied over the years. Most recently, Canada has committed to contribute C$2.65 billion between 2016 and 2021 towards global climate finance (Government of Canada, 2018). Between 2016 and 2018, Canada ranked 9th among 24 OECD contributors to climate finance (Tomlinson, 2020). Canada's ranking for this period drops to 14th among 24 OECD donors when taking into account the contribution of climate finance relative to countries' Gross National Income (Tomlinson, 2020). Tracking climate finance flows is an inexact science (Furlow et al., 2011), not least because it can be impractical to isolate the additional finance destined for climate action—particularly when tracking climate finance for adaptation, given the strong linkages between adaptation and broader development investments (Church and Hammill, 2019). Transparency in climate finance tracking and reporting is a standing focus of work for the UNFCCC and OECD (Clapp et al., 2012).

Canada is taking steps to build the resilience of developing countries through development and assistance programming. Over 2017 and 2018, Canada delivered C$1.5 billion to developing countries for climate action—of which C$704 million was part of the Government of Canada's C$2.65 billion climate finance commitment; C$246 million was part of the Government of Canada's regular international assistance projects with a climate change component; C$17 million was associated with provincial and municipal support; C$509 million was provided from Export Development Canada by mobilizing private finance; and US$30 million was delivered by FinDev Canada, a newly established development finance institution (Government of Canada, 2020). Of these investments, C$192 million targeted climate change adaptation, as compared to C$315 million for GHG emissions reduction initiatives, and C$498 million was dedicated to initiatives that cut across adaptation and GHG emissions reduction priorities. This adaptation investment includes Canada's C$30 million contribution to the Least Developed Countries Fund, which addresses urgent adaptation needs of the least wealthy and most vulnerable countries. Projects funded by Canada include C$100 million in support of the expansion of climate risk insurance coverage in climate-vulnerable countries, with the aim of helping communities build back better and faster following disasters related to natural hazards such as hurricanes and flooding (Government of Canada, 2020). Current top recipients of Canadian official development assistance—Haiti, Mali, South Sudan, Syria, and Tanzania—are projected to experience significant climate impacts in the years ahead. This underscores the potential for increased demands for climate-related development assistance in the years to come. Case Story 9.4 in the previous section illustrates how climate change may have played a part in increasing demands for Canada's assistance by Mali.

In line with the Feminist International Assistance Policy, Canada's climate finance investments have a strong focus on gender equality and on the empowerment of women and girls. Attention to gender equality is important as evidence shows females and males differ in their vulnerability to climate change and preferences for adaptation solutions, with women and girls continuing to be disproportionately impacted by the adverse effects of climate change (Rao et al., 2019; Assan et al., 2018; Vincent et al., 2010). Projects that are gender-blind have the potential to increase disparities between the sexes and perpetuate structural challenges that limit access to resources and power.

Canada has also contributed to building knowledge and local research capacity on vulnerability to climate change impacts and feasible adaptation options in developing countries. One example is the body of research produced through the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA), jointly funded by Canada's International Development Research Centre (IDRC) and the United Kingdom's Department for International Development (International Development Research Centre, 2019). Alongside many other initiatives led by the IDRC, this collaborative effort is yielding lessons, good practices and innovations applicable to Canada's future investments in development assistance (*see* Case Story 9.5). These lessons include practical approaches to integrate disaster risk reduction and climate change adaptation into project and program designs centred on local contexts to encourage the pursuit of low-carbon benefits and also to avoid inducing maladaptation (UN Environment Programme, 2017; Adger et al., 2014).

Case Story 9.5: Researching risk-pooling initiatives in the face of climate change in South Africa

Floods are a common and damaging climate-related hazard in South Africa (Zuma et al., 2012). In the Western Cape, for example, expected urban damage per year is estimated to be US$66 million (World Resources Institute, 2017). South Africa's Disaster Risk Financing strategy is primarily focused on a form of self-insurance. Climate change will test the resilience of this strategy. The use of risk-transfer tools, such as risk-pooling, is an option to increase the financial capacity of provincial governments if losses become exorbitant. Risk pooling has the potential to extend coverage to those individuals who are not covered by commercial insurance, and thereby acts as a safety net.

Funded by Canada's International Development Research Centre (IDRC), the Municipal Risk Pooling project (IDRC, 2020) is examining the feasibility of developing subnational risk pools as a mechanism for managing climate risk, with the aim of generating guidance for others. It is led by the University of KwaZulu-Natal, endorsed by the Western Cape subnational government and involves a number of partners, including SouthSouthNorth and the Munich Climate Insurance Initiative.

Figure 9.12 illustrates the proposed structure for a Municipal Risk Pooling project. A risk-pooling facility based at the municipal level would allow South African entities to accrue all benefits from premiums paid, with governance and decision-making power retained within South Africa. Under this model, municipalities pay premiums towards the risk pool (either from their own budget or supported by donors), determined by the type of coverage required (e.g., 1-in-5-year event) and the risk profile of the municipality. Participating in risk pools could allow local governments to access insurance on better terms than if they applied as an individual entity. The risk pool would grow the capital reserves over time through investments that yield returns, while also reducing exposure of the pool by passing on risks to reinsurance and capital markets.

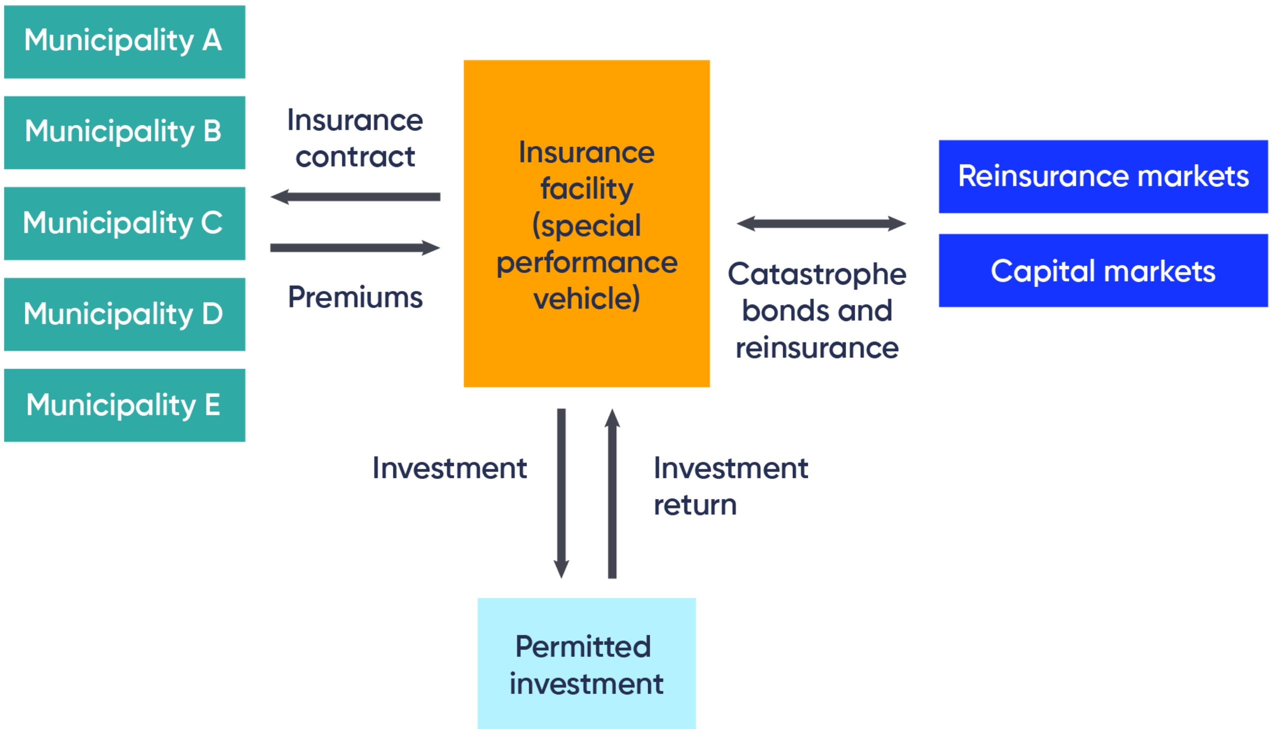


Figure 9.12: A proposed structure for the Municipal Risk Pooling Facility project led by the University of KwaZulu-Natal.

9.7 Moving forward

9.7.1 Knowledge gaps and research needs

Research on the risks and opportunities to Canada stemming from climate change impacts, events and adaptation that occur or are amplified beyond Canadian borders remains underdeveloped. All of the topics discussed here—tensions over Arctic sovereignty as sea ice retreats; the potential for strained relationships from climate-induced shifts in freshwater flows and marine resources shared across international boundaries; economic impacts to Canada due to changes in global trade exacerbated by extreme events and climate change; the potential for increased pressure on Canada's immigration and resettlement infrastructure; as well as demand for Canadian international assistance—are within the top twelve climate risk areas identified for

Canada (Council of Canadian Academies, 2019). Defence and foreign policies acknowledge the role of climate change in exacerbating existing vulnerabilities in the Arctic and fragilities in some countries as well as the need for enhanced capabilities to address increased demands. Climate-related disruptions in global supply chains highlight the potential for trade to propagate or dampen economic risk, and widespread adoption of climate-related financial disclosure by firms in Canada's trade sectors may well yield the data needed to understand the degree to which product, market, logistics, security and other dynamics interact with climate change risk. Agencies managing transboundary resource-sharing agreements are starting to revisit assumptions of static environmental conditions, since these risk unsustainable resource use and threaten the stability of cooperative relationships. Despite a growing awareness of the international dimensions of climate change risk for Canada, the knowledge base is insufficient to reliably assess the extent of current and future risk exposure as climate change intensifies. This assessment relied on a number of strands of research and evidence; in some cases, there was a continued need to make inferences.

Nevertheless, with the evidence available it is possible to highlight early indicators for decision makers to respond to, while academic and practitioner communities continue to address knowledge gaps. Table 9.13 provides a qualitative account of the likelihood of risk factors described in previous sections of this chapter. There is least confidence in risk factors related to international trade.

Table 9.13: Qualitative assessment of risks and opportunities to Canada from transboundary impacts of climate change over the next 30 years

RISK/OPPORTUNITY FACTOR	LIKELIHOOD	CONFIDENCE
Arctic shipping and sovereignty		
Decreased extent, thickness and age of summer sea ice in the Arctic Ocean and gradual opening up of major waterways to ice-free conditions for part of the year		
Increased physical access to Canada's Arctic resources and waters		
Increased vessel traffic in Canadian Arctic waterways, including in the Northwest Passage		
Development of economically competitive and safe Arctic shipping and trade routes		

RISK/OPPORTUNITY FACTOR	LIKELIHOOD	CONFIDENCE
Increased perception of the Northwest Passage as an international strait linked to substantial rise in commercial shipping		
Diminished Canadian ability to use Article 234 under the UN Convention of the Law of the Sea for legitimacy over regulation of Northwest Passage waters		
Increased pollution, oil spills and negative impacts on marine habitats due to shipping in the Northwest Passage		
Diminished capacity to enforce environmental protections in Canada's Arctic waterways linked to inadequate infrastructure and operations		
Transboundary marine and freshwater agreements		
Increased migration of marine species poleward or to deeper water, resulting in redistribution of marine species across borders		
Changes in water quantity and timing of flows, water temperatures, and intensity, frequency and/or duration of floods and droughts, resulting in spatial and temporal redistribution of freshwater resources across borders		
Changes in perceived benefits from resource sharing, partly driven by regional differences in climate change impacts and vulnerabilities		
Increased uncertainty of meeting management objectives under existing transboundary cooperative structures		
Increased need for difficult trade-offs across competing freshwater water uses		
Increased application of adaptive measures in most key Canada–U.S. freshwater agreements (beyond the Great Lakes Water Quality Agreement)		

RISK/OPPORTUNITY FACTOR	LIKELIHOOD	CONFIDENCE
International trade		
Increased economic impacts to Canada through disruptions to supply chains and distribution networks		
Increased resilience of new and existing trade infrastructure networks worldwide		
Increased global markets for adaptation solutions		
Changes in the availability and prices of basic goods, including disruptions to the global food system		
Increased spread of economic risk to Canada through climate change impacts to major trade partners		
Increased relative gains to Canada from long-term shift in trade patterns		
Increased global disparities from the unequal adaptive effect of trade		
Human migration and displacement		
Increased displacement of millions of people each year around the world due to tropical cyclones, floods, droughts, wildfires and food insecurity, combined with non-climate stressors		
Increased future demand for immigration to Canada from countries highly exposed to climate risk, especially from Canada's largest source countries of international migrants		
Increased skilled worker migration to Canada from climate-disrupted regions		
Increased pressure to provide financial assistance for refugee procedures and serve as a resettlement destination		

RISK/OPPORTUNITY FACTOR	LIKELIHOOD	CONFIDENCE
Evolution of climate-related migration arrivals into Canada shaped by disparate immigration and border policies between Canada and the United States		
International assistance		
Increased future demand for international assistance, including responding to humanitarian crises, particularly in countries where Canada is already active		
Increased need for international assistance to address root causes of involuntary climate migration		
Increased future demand for intervention in water scarce, politically unstable Least Developed Countries		

Note: Likelihood is represented on a graduated colour scale: dark green = negligible, light green = unlikely, yellow = possible, orange = likely, and red = almost certain. Confidence is represented on a 4-point scale, with grey = unclear, green = low, yellow = medium, and red = high. Confidence ratings take into account the extent of evidence and relative influence of non-climate drivers. The likelihood and confidence scores were based on the expert opinion of the author team.

Based on the assessment in this chapter, four emerging themes stand out as needing further consideration as adaptation science and knowledge evolves in Canada.

9.7.1.1 Governance and mainstreaming

Academic and practitioner research recognizes the advantages of advancing adaptation through its integration into existing institutions, policy and planning processes (e.g., Lemmen et al., 2008). Mainstreaming is a strategy promoted in each of the discussions in this chapter and is a concept tightly connected to governance. Each topic addressed in this chapter has its own web of actors and institutions already governing the evolution of each system at different scales. International agreements (e.g., transboundary river basin treaties) and customary laws (e.g., UNCLOS), multi-lateral institutions (e.g., Arctic Council, World Trade Organization, trade agreements), national or subnational policies (e.g., trade, military defence, immigration, international assistance), and sectoral or organizational strategies all form part of issue governance. Governance is itself dynamic and subject to shifts in societal expectations, politics, social norms and review schedules, among others, such that adaptation mainstreaming can occur within a moving target. This can include the need to dismantle or modify existing institutions and create new ones where none exist. Options for increasing consideration of indirect, cross-border climate change impacts in adaptation governance include: 1) national or bilateral responses that, for example, aim to increase self-sufficiency and ensure cooperation among strategic partners; 2) transnational responses characterized by leadership of non-state actors; and 3) international responses focused on reforming existing institutions, including expanding the mandate of the UNFCCC (Benzie and Persson, 2019).

At present, key issues gaining prominence in governance in Canada that also shape adaptation governance include reconciliation with Indigenous peoples and the rise of populist politics. The former has fundamental implications for resource use and development, among other domains. For example, for Inuit peoples, Arctic sovereignty is connected to self-determination, the right to cultural integrity and empowerment (Inuit Circumpolar Council, 2009). Addressing these issues requires supporting healthy and sustainable communities informed by Inuit needs and knowledge (Gerhardt, 2011) and cooperating with governments in setting the rules for Arctic development (Dodds and Hemmings, 2015). Shifts in Canadian public sentiment in favour of populism can temper Canada's role as a destination for migrants from climate-disrupted regions and as a source of international development assistance tagged for adaptation and resilience. Insular attitudes of the Canadian public may also diminish political will to act on Canada's commitment to multilateralism and step in as a global broker of cooperative solutions. With increased pressure to deliver results from public budgets, knowledge about the effectiveness and equity impact of adaptation efforts funded by governments is critical. At the same time, coherence among all parts of Canada's international policies with respect to climate, trade, migration, international assistance and security efforts will become increasingly important.

9.7.1.2 Global food systems

Combined with other pressures, such as population growth and shifting diets, climate change threatens global food systems, with implications for food security. Food security is a multi-dimensional concept comprising availability (quantity), access (physical and financial), utilization (nutrition) and stability (Food and Agriculture Organization, 2018). Although all dimensions are subject to climate change threats, quantitative studies focus on availability and, to a lesser extent, access. Canada's role in supporting food security outside its borders now and in the future, including as a net exporter of fertilizer, grains, fish and seafood, through international assistance and through partnered research merits closer consideration. The role can be explored from several dimensions, including economic interest, global stability and contributions to meeting the 2030 United Nations Agenda for Sustainable Development. In examining Canada's potential contribution to future food availability, access and stability, a more balanced view than what is captured in global modelling efforts may be needed to estimate the impact of climate change on food production in Canada and what this means for exports. For example, Canadian agricultural producers will face a mix of opportunities and challenges (*see* Sector Impacts and Adaptation chapter), and the aggregate functions included in studies such as Dellink et al. (2017) can fail to capture realistic impacts on Canada's agricultural productivity and nutritional content. A lack of research on how the impacts of climate change elsewhere in the world could affect food supplies in Canada is an important knowledge gap, since consumer choices could be restricted as food exports from tropical countries become less reliable.

9.7.1.3 Assessment tools that accommodate uncertainty and complexity

For many years, Canadian and international research has recognized that climate change vulnerability and decisions to adapt are rarely shaped by climate factors alone (IPCC, 2007). This conclusion aptly applies to understanding the international dimensions of climate change risk for Canada and how Canadians should adapt. Assessment of all issues in this chapter emphasized that climate change and its impacts are rarely the sole risk driver or reason for adaptation. For example, resource markets, technology and strategic interests are important drivers of shipping in Arctic waterways; disappearing sea ice only enables shipping activity. Population migration is the cumulative result of environmental, social, economic and cultural factors. Although some climate hazards directly displace people (e.g., hurricanes), the role of climate variability or climate change in motivating population movement is not always clear. Because of the complexity in both assessing and managing risks (and opportunities) resulting from the interactions of multi-layered cause-and-effect chains, decision makers may need assistance to define the problem. This can include clarifying the outcomes they wish to safeguard, isolating the drivers most likely to threaten or enrich these outcomes, implementing and monitoring management actions targeting drivers over which they have some control or ability to predict and tracking the evolution of other drivers. Use of foresight tools (e.g., scenario planning and horizon scanning) as well as holistic approaches, like systems mapping (e.g., Cradock-Henry et al., 2020) and cumulative effects assessment, which combine climate and non-climate drivers and outcomes in one framework, will help to bound the range of probable outcomes and management levers worth pursuing. Capacity for systems thinking, adaptive leadership and iterative learning are all important qualities of decision makers navigating large-scale transformations (Eyzaguirre et al., 2017).

9.7.1.4 Strengthened economic modelling

Aside from improvements in modelling the agriculture and food sector, strengthening the breadth and depth of economy-wide modelling efforts in Canada would help improve its overall assessment of economic risk. A knowledge gap exists in the analysis of the economic impacts of climate change on patterns of domestic production, as it does in the analysis of the projected impacts on the economies of the regions with which Canadian producers compete in international markets. Studies such as those carried out by Szewczyk et al. (2018), who modelled the spillover effects of climate impacts occurring outside the EU but affecting the EU via trade, and by Zhang et al. (2018), who modelled the spillover effects of climate impacts occurring in the United States affecting other global regions via trade, provide foundations to build on, as do assessments undertaken in Germany and Switzerland (Stockholm Environment Institute, 2018).

9.8 Conclusion

This chapter focused on risks and opportunities facing Canada from indirect impacts of climate change with international dimensions. For all issues considered, the research remains underdeveloped, particularly as it relates to international trade. Indirect impacts of climate change have long been neglected in Canadian adaptation research, partly because of the methodological complexities and multiple disciplines involved. Although adaptation—planned or proactive—is either not documented or not yet occurring in a consistent way across the policy and management issues assessed, there are examples of spontaneous or market-driven adaptation. The increase in Arctic shipping, migration decisions in response to climate-related disasters and diversification of raw material suppliers are just a few examples. It is challenging to assess the significance of excluding these transboundary, teleconnected or cascading effects in measuring Canada's progress in adapting to climate change. Nevertheless, the information presented in this chapter sheds light on the potential perils of lagging behind in laying the groundwork for adaptation and in addressing the weaknesses in resilience and adaptive capacity that have already been identified (e.g., for Arctic shipping and sovereignty as well as transboundary resource management). In any case, without deep cuts in global GHGs to limit future climate change, it will become increasingly costly and challenging to sustain Canadians' well-being in a climate-disrupted world (Curtin, 2019).

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