Canada's Top Climate Change Risks

The Expert Panel on Climate Change Risks and Adaptation Potential

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ASSESSING **EVIDENCE**
INFORMING **DECISIONS**

CANADA'S TOP CLIMATE CHANGE RISKS

The Expert Panel on Climate Change Risks and Adaptation Potential

THE COUNCIL OF CANADIAN ACADEMIES
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Notice: The project that is the subject of this report was undertaken with the approval of the Board of Directors of the Council of Canadian Academies (CCA). Board members are drawn from the Royal Society of Canada (RSC), the Canadian Academy of Engineering (CAE), and the Canadian Academy of Health Sciences (CAHS), as well as from the general public. The members of the expert panel responsible for the report were selected by the CCA for their special competencies and with regard for appropriate balance.

This report was prepared for the Government of Canada in response to a request from the Treasury Board of Canada Secretariat. Any opinions, findings, or conclusions expressed in this publication are those of the authors, the Expert Panel on Climate Change Risks and Adaptation Potential and do not necessarily represent the views of their organizations of affiliation or employment, or the sponsoring organization, the Treasury Board of Canada Secretariat.

Library and Archives Canada

ISBN: 978-1-926522-67-8 (electronic book) 978-1-926522-66-1 (paperback)

This report should be cited as:
Council of Canadian Academies, 2019. *Canada's Top Climate Change Risks*, Ottawa (ON): The Expert Panel on Climate Change Risks and Adaptation Potential, Council of Canadian Academies.

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Printed in Ottawa, Canada

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Canada This assessment was made possible with the support of the Government of Canada.

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All CCA assessments undergo a formal peer review and are published and made available to the public free of charge. Assessments can be referred to the CCA by foundations, non-governmental organizations, the private sector, or any level of government.

The CCA is also supported by its three founding Academies:

The Royal Society of Canada (RSC)
Founded in 1882, the RSC comprises the Academies of Arts, Humanities and Sciences, as well as Canada's first national system of multidisciplinary recognition for the emerging generation of Canadian intellectual leadership: The College of New Scholars, Artists and Scientists. Its mission is to recognize scholarly, research, and artistic excellence, to advise governments and organizations, and to promote a culture of knowledge and innovation in Canada and with other national academies around the world.

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The Expert Panel on Climate Change Risks and Adaptation Potential and Workshop Participants

Under the guidance of its Scientific Advisory Committee, Board of Directors, and the Academies, the CCA assembled the Expert Panel to lead the design of the workshop, complete the necessary background research, and develop the report. The Panel directed the CCA in identifying the experts who participated in the workshop. Each expert was selected for his or her expertise, experience, and demonstrated leadership in fields relevant to this project.

Expert Panel

L. John Leggat, FCAE (Chair), Former Assistant Deputy Minister, Science and Technology, Department of National Defence (Ottawa, ON)

Elizabeth Beale, Former President and CEO, Atlantic Provinces Economic Council; Commissioner, Canada's Ecofiscal Commission; and Associate, Harris Centre for Regional Policy, Memorial University of Newfoundland (St. John's, NL)

Pierre Gosselin, Consulting Physician, Institut national de santé publique du Québec; Clinical Professor, Université Laval and Institut national de la recherche scientifique; Coordinator, Health Program, Ouranos; Director, WHO/PAHO Collaborating Centre on Environmental and Occupational Health at CHU de Québec-Université Laval (Quebéc, QC)

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Roger B. Street, Research Fellow, Environmental Change Institute, University of Oxford (Oxford, United Kingdom)

The CCA also recognizes the important contribution of **Barry Smit, O. Ont., FRSC,** Professor Emeritus, University of Guelph (Guelph, ON).

Workshop Participants

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Greg Paoli, Principal Risk Scientist and Chief Operating Officer, Risk Sciences International, Inc. (Ottawa, ON)

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Elaine Wheaton, Climate Scientist and Adjunct Professor, University of Saskatchewan; Researcher Emeritus, Saskatchewan Research Council (Saskatoon, SK)

Angie Woo, Lead, Climate Resilience & Adaptation, Fraser Health (Vancouver, BC)

Message from the Chair

Recent reports point out that Canada is warming at a rate roughly double that of the rest of the world. For northern parts of the country the warming trend is nearly three times the world rate. Global greenhouse gas concentrations continue to increase spurred by global energy use which increased at a rate of 2.3% in 2018. The burning of fossil fuels provided the energy for most of this increase. Global emissions will continue to rise, and Canada's warming will continue its upward trend.

Continued efforts to reduce greenhouse gas emissions in Canada help do our part, and demonstrate our commitment to the Paris Accord and to global emissions reduction. Importantly, our demonstration of mitigation action at home also bolsters our efforts to encourage others to reduce. Even with our best efforts, however, the climate will continue to change in Canada, meaning adaptation will become an increasingly important matter. Understanding our top climate change risks and identifying how to manage and adapt to them will help reduce the impact of climate change on people in Canada.

This assessment responds to two important questions from the Treasury Board of Canada Secretariat: What are the top climate change risks for Canada, and which have the most potential to be minimized by adaptation measures? The findings emerged from expert opinions and insights of the workshop participants and Panel members, underpinned by extensive research of evidence in the literature. The report also examines risk assessment criteria and federal government roles and decision-making pertaining to adaptation to climate change. Given the limited time and effort available, the Panel chose breadth over depth and has produced a balanced view of both the climate change risks faced by Canada and their associated adaptation potential.

The Panel is of the view that assessments of this kind need to be conducted at regular intervals to track the evolution of risks and to monitor the implementation and effectiveness of adaptation measures.

On behalf of the Panel members, I thank the CCA for inviting us to participate in this assessment. The Panel was indeed fortunate to have such a qualified and motivated team from the CCA to support our work and I can say with confidence that the Panel is very appreciative of their dedication and wonderful work. I believe that I speak for the Panel and the CCA team when I say that we found the work challenging and inspiring. I am very appreciative of the outstanding qualities and participation of the Panel members. Their willingness to suggest, challenge, and come together on important issues made my job as Chair both manageable and enjoyable. My sincere thanks to each and my best wishes to them all for their future endeavours.

L. John Leggat, FCAE, Chair
Expert Panel on Climate Change Risks and Adaptation Potential

Message from the CCA President and CEO

Climate change poses complex and interconnected risks to people and the planet, so it should be no surprise that Canada is subject to climate change risks that span almost every facet of life. While many studies have been conducted about climate change risks at the sectoral and departmental level, no assessment has specifically focused on helping the federal government prioritize its adaptation responses. This knowledge gap was highlighted in a 2018 report of federal, provincial, and territorial Auditors General. It was against this backdrop that the Treasury Board of Canada Secretariat asked the Council of Canadian Academies (CCA) to undertake the present study.

The CCA convened an Expert Panel of seven distinguished domestic and international experts from diverse backgrounds including economics, human health, earth sciences, social sciences, and climate change adaptation and risk assessment. Their expertise was augmented by a workshop at which an additional 17 experts contributed their knowledge and insights. The ensuing report, *Canada's Top Climate Change Risks*, identifies the top climate risks for Canada, assesses which risks have the greatest potential for adaptation, and explores how the federal government can best inform its decision-making in response to these risks.

The Panel was chaired by Dr. L. John Leggat, FCAE, to whom I extend my sincere thanks, along with the Expert Panel members and workshop participants. As with every CCA assessment, the CCA Board of Directors, Scientific Advisory Committee, and the three founding Academies — the Royal Society of Canada, the Canadian Academy of Engineering, and the Canadian Academy of Health Sciences — provided key guidance and oversight during the assessment process. I thank them for their support.

Finally, I would like to thank the Sponsor, the Treasury Board of Canada Secretariat, together with the other federal departments that supported this assessment – Agriculture and Agrifood Canada, Environment and Climate Change Canada, Infrastructure Canada, Natural Resources Canada, and Transport Canada – for referring this important topic to the CCA.

Eric M. Meslin, PhD, FCAHS
President and CEO, Council of Canadian Academies

Acknowledgements

Over the course of its deliberations, the Panel sought assistance from many individuals and organizations that provided valuable information for consideration. Special thanks go to the following: Matthew Godsoe, Public Safety Canada, Cody Anderson, Public Health Agency Canada, and Graeme Reed, Assembly of First Nations.

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With assistance from:	Erik Lockhart, Workshop Facilitator Jack Satzewich, Research Consultant Jody Cooper, Editor François Abraham, Communications Léon Inc., Certified translator, Translation English-French Marc Dufresne, Report Design, CCA

Peer Review

This report was reviewed in draft form by reviewers selected by the CCA for their diverse perspectives and areas of expertise.

The reviewers assessed the objectivity and quality of the report. Their confidential submissions were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the CCA.

The CCA wishes to thank the following individuals for their review of this report:

Gordon Beal, Vice President, Research, CPA Canada (Toronto, ON)

Sherilee L. Harper, Associate Professor and Canada Research Chair in Climate Change and Health, School of Public Health, University of Alberta (Edmonton, AB)

Peter Harrison, Professor Emeritus, Queen's University (Kingston, ON)

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Christopher Kennedy, Professor and Chair, Department of Civil Engineering, University of Victoria (Victoria, BC)

Jason Thistlethwaite, Assistant Professor, University of Waterloo (Waterloo, ON)

Kyle Whyte, Professor, Michigan State University (East Lansing, MI)

The peer review process was monitored on behalf of the CCA's Board of Directors and Scientific Advisory Committee by **Jackie Dawson,** Canada Research Chair in Environment, Society and Policy, and Associate Professor, Department of Geography, University of Ottawa. The role of the peer review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the peer reviewers. The Board of the CCA authorizes public release of an expert panel report only after the peer review monitor confirms that the CCA's peer review requirements have been satisfied. The CCA thanks Dr. Dawson for her diligent contribution as peer review monitor.

Key Findings

The Panel identified 12 major areas of climate change risk facing Canada from a national perspective, all of which could involve significant losses, damages, or disruptions over the next 20 years. In the Panel's judgment, the top six areas of climate change risk are: physical infrastructure; coastal communities; northern communities; human health and wellness; ecosystems; and fisheries.

Canada's climate is changing. Since 1948, Canada's annual average temperature over land has increased by approximately 1.7°C — roughly double the global average level of warming. Higher temperatures have been accompanied by 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; avoiding scenarios with large and rapid warming will require Canada and other countries to reduce carbon emissions to near zero by early in the second half of the 21st century.

Charged by the federal government with identifying the top areas of climate risk facing Canada on a national scale, the Panel assessed a wide range of evidence on climate change impacts and risks. Building on a review of published studies and insights from an expert workshop, the Panel identified 12 major areas at risk from climate change: agriculture and food; coastal communities; ecosystems; fisheries; forestry; geopolitical dynamics; governance and capacity; human health and wellness; Indigenous ways of life; northern communities; physical infrastructure; and water. Risks were found to be substantial in all 12 of these areas, and liable to lead to significant losses, damages, or disruptions in Canada over a 20-year timeframe. Cutting across these risk areas, climate change poses significant risks for Canadian businesses and the economy as a whole, and costs are already being incurred. However, based on consideration of expected consequences of climate change and the risks' likelihood of occurrence, the Panel found Canada's climate change risks to be the highest in the six areas in Table 1.

Table 1

Top Six Areas of Climate Change Risk Facing Canada

Area of Risk	Description
Physical Infrastructure	Risks to physical infrastructure in Canada from extreme weather events, such as damage to homes, buildings, and critical infrastructure from heavy precipitation events, high winds, and flooding; increased probability of power outages and grid failures; and an increasing risk of cascading infrastructure failures.
Coastal Communities	Risks to coastal communities in Canada, including damage to coastal infrastructure, property, and people from inundation, saltwater intrusion, and coastal erosion due to sea-level rise and storm surges.
Northern Communities	Risks to northern communities and people in Canada, including damage to buildings, roads, pipelines, power lines, and airstrips due to thawing permafrost; reduced or disrupted access to communities and facilities due to warmer temperatures; and increased risks from marine accidents due to increased marine traffic and reduced summer sea-ice extent.
Human Health and Wellness	Risks to human health and wellness in Canada, including adverse impacts on physical and mental health due to hazards accompanying extreme weather events, heatwaves, lower ambient air quality, and increasing ranges of vector-borne pathogens.
Ecosystems	Risks to Canadian ecosystems and species, including threats to biodiversity, ecosystem resilience, and the ability of ecosystems to provide a range of benefits to people such as environmental regulation, provision of natural resources, habitat, and access to culturally important activities and resources.
Fisheries	Risks to Canadian fisheries and fish stocks, including declining fish stocks and less productive/resilient fisheries due to changing marine and freshwater conditions, ocean acidification, invasive species, and pests.

Climate change risks are complex and interconnected, and impacts can propagate through natural and human systems in ways difficult to anticipate.

Climate change risks are often interconnected, cutting across natural and human systems. In particular, climate change impacts on physical infrastructure, water, and ecosystems can have cascading consequences for many other areas, including the natural and human systems that depend on them. For instance, flooding from heavy rain and storm surges poses risks to infrastructure, which can interfere with human health and wellness by disrupting access to health and social services, and affect water quality through damage to water treatment and distribution systems. Flooding can also affect governance and capacity when existing systems fail to manage an infrastructure disruption or are themselves compromised by such failures. Heatwaves create health risks (especially for vulnerable populations), which can be managed with appropriate infrastructure (e.g., building design, air conditioning, healthcare systems, electricity grids). Degradation and loss of biodiversity and ecosystems, and the services they provide, can exacerbate risks caused by floods and heatwaves — such as loss of water and food security — but also create other complex impacts that may not yet be well understood or adequately characterized.

These connections and interdependencies makes climate change risk analysis, and adaptation planning and implementation, challenging. The 12 major areas of climate change risk assessed by the Panel are interconnected, often through multiple channels, and more research would help to improve understanding of the relationships among these areas. There is increasing recognition of the pervasive effects of climate change on Canada's economy — be it through damage to homes caused by flooding, supply chain disruptions resulting from changing water levels along shipping routes, or business, industry and employment disruptions associated with extreme events and wildfires — but major gaps in understanding remain and would benefit from additional research and increased collaboration. Uncertainty about the future as well as potential cascading impacts call for additional caution in the application and interpretation of risk assessment results.

All 12 areas of risk considered by the Panel can be meaningfully reduced through adaptation measures that lessen vulnerability or exposure.

In all cases, adaptation actions (or a portfolio of actions) can reduce the damage or costs associated with climate change. However, no risk can be completely eliminated through adaptation alone. Thus, decision-makers need to anticipate and plan for consequences that are unavoidable in the short and medium term, while working to reduce future GHG emissions globally. Climate risks to natural systems on which all life depends are often more difficult to manage than risks to human systems; in many cases, climate change is advancing too fast for natural systems to keep pace. Measures to preserve and enhance ecosystem resilience through conservation, restoration, and improved resource management practices could support adaptation in natural systems. The effectiveness of adaptation actions can be maximized by: (i) considering systemic interconnections across risks in the design of their adaptation strategies; (ii) phasing out and avoiding maladaptive actions (i.e., actions that increase emissions or exacerbate risks in other areas); (iii) taking advantage of windows of opportunity for adaptation progress; (iv) factoring social context, cost, and technical feasibility into the evaluation of adaptation opportunities; and (v) favouring adaptation options with co-benefits for emissions reduction and other policy objectives.

Understanding the climate change risks facing Indigenous Peoples in Canada requires a deeper exploration of these risks and associated adaptation potential, consistent with the spirit of reconciliation.

Indigenous ways of life is a unique area of risk, one that merits further assessment through an inclusive and reflective process together with Indigenous Peoples. The Assembly of First Nations, Inuit Tapiriit Kanatami, and Métis National Council have documented their expectations for what constitutes acceptable engagement. Future climate risk assessments would benefit from a comprehensive process, potentially co-designed by and co-executed with Indigenous participants.

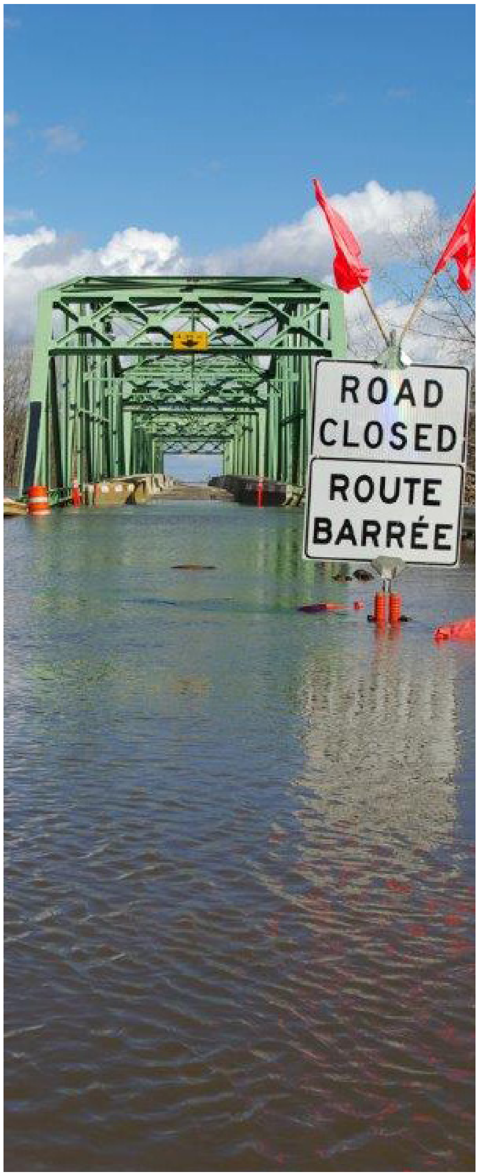
Risks to Indigenous ways of life from climate change include, but are not limited to, loss of opportunities to practise cultural activities such as hunting, fishing, and foraging due to ecosystem changes; increased risk of physical harm associated with some activities (e.g., hunting on thin or less predictable sea ice); loss of intergenerational cohesion and cultural integrity due to changing environmental conditions and impacts on traditional activities; and loss of culturally significant sites to coastal erosion, sea-level rise, and other types of flooding.

Indigenous Peoples have demonstrated a capacity for adaptation, resilience, and survival in the face of pervasive social, cultural, and environmental changes over the course of colonial history. Multiplicative effects of climate change, when combined with the effects of colonialism, power differentials in Canadian society, marginalization, and loss of land may, however, affect adaptation success.

Governments in Canada can play a role in enhancing capacity through additional support and investment as they work with Indigenous Peoples to develop socially, culturally, and economically relevant adaptation practices. Collaboration and coordination efforts would ideally be grounded in a rights-based approach, consistent with the spirit of reconciliation.

Federal responses to each of the 12 areas of climate change risk can be informed by prioritizing actions within and across three main categories: coordination and collaboration, capacity building, and assets and operations.

All 12 areas of risk identified by the Panel can benefit from additional federal risk-management actions given the scale of potential negative consequences. However, adaptation actions can also be pursued by all governments (federal, provincial/territorial, Indigenous, and local), businesses and industries, non-profit organizations, communities, and individuals to ensure that the worst damages and greatest losses stemming from climate change are avoided. Processes to decide on action required to manage risk are often driven by perceptions of urgency. National planning and prioritization for adaptation to climate change risks could also be served by a comprehensive understanding of the federal government's role in each risk area. Adaptation could be accomplished through coordination and collaboration, capacity building, or managing government assets and operations. This would ensure no major areas of risk are neglected and that government resources are allocated based on a detailed assessment of adaptation roles, needs, and urgency, while acknowledging that the federal government will rarely be acting alone in managing these risks.



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1 Introduction

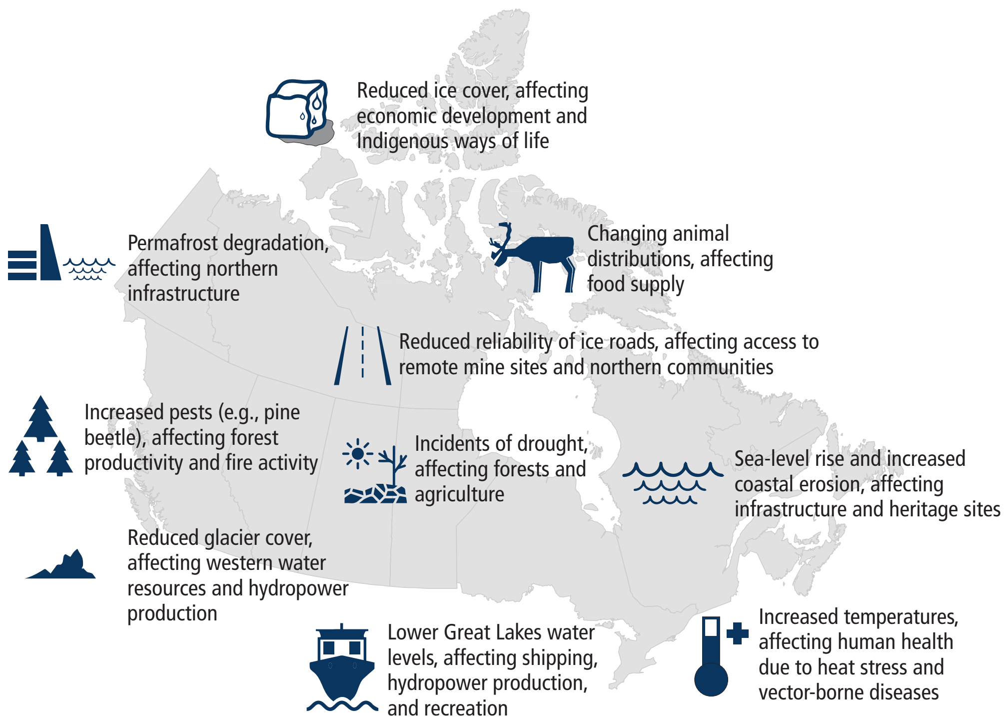
Many indicators now show unequivocally that Canada's climate is changing. Since 1948, Canada's annual average temperature over land has increased by approximately 1.7°C — roughly double the global average level of warming (Bush & Lemmen, 2019). Average annual precipitation has also increased in many areas, and there has been a shift in precipitation type from snow to rain. In northern Canada, temperature increases have been even higher, rising 2.3°C since 1948 (Bush & Lemmen, 2019). Summer sea ice could be largely absent from the Arctic Ocean by the late 2030s (AMAP, 2017), posing threats to a range of species including seals, walrus, and polar bears. Permafrost is warming and thawing, and glaciers in both the Arctic and the western mountains are shrinking, with consequent impacts on runoff and water systems now and in the future (Bush, 2014; Bush & Lemmen, 2019). Many of these changes have accelerated in recent decades as global greenhouse gas (GHG) emissions increased (Bush & Lemmen, 2019).

Such changes are already having widespread impacts on natural systems across Canada (Warren & Lemmen, 2014a) (Figure 1.1). Shifts in the geographic distribution of some species of birds, butterflies, and trees have been observed. Many bird populations appear to be in decline; tree mortality has increased due to higher rates of forest disturbance such as insect infestation, drought, and fire; and mortality has also increased in some fish stocks, shellfish, and other marine species in response to higher water temperatures, ocean acidification, and low oxygen levels (Warren & Lemmen, 2014a).

Climate change is also increasingly leading to costly and disruptive impacts on human systems. For example, insured losses associated with extreme weather events in Canada rose from an average of $405 million per year between 1983 and 2008 to $1.8 billion per year between 2009 and 2017 (Feltmate, 2018), with the greatest losses arising from flooding. Indigenous and northern communities have been affected in distinctive ways: climate change has disrupted access to these communities, threatened cultural sites, and adversely affected people's ability to practise traditional activities such as hunting, fishing, and foraging (Furgal & Prowse, 2008; Ford *et al.*, 2016a). In the Arctic, the health and well-being of local communities is being affected as climate change compromises the availability of traditional foods and water supplies (Bell & Brown, 2018). Such impacts are projected to continue and intensify in the absence of significant reductions in GHG emissions (Melillo *et al.*, 2014; Bush & Lemmen, 2019).

Governments across Canada, from the local to the national level, are increasingly aware of these impacts, and have started taking action to manage climate-related risks. While many governments have undertaken climate risk assessments for individual sectors or departments, few have current, government-wide risk assessments that could help prioritize their response to risks across their sphere of operations. According to a 2018 report from federal and provincial/territorial Auditors General, most governments are not taking sufficient steps to identify, manage, and reduce the risks arising from climate change (OAG, 2018a). The Auditors General found that most governments either had no adaptation plan or their plan lacked basic details such as timelines. The report states that "most Canadian governments have not assessed and, therefore, do not fully understand what risks they face and what actions they should take to adapt to a changing climate" (OAG, 2018a).

The April 2019 release of *Canada's Changing Climate Report* represents the first in the latest set of federal government-led assessments intended to enhance understanding of climate change, impacts, and adaptation, and will be followed by assessments on national issues, regional perspectives, and health (NRCan, 2019a). At the federal level, the *Federal Adaptation Policy Framework* provides guidance for identifying climate change adaptation priorities (GC, 2011), and the *Pan-Canadian Framework on Clean Growth and Climate Change* provides direction for intergovernmental adaptation efforts, outlining shared priorities (GC, 2017a). To date, however, these efforts have been undertaken in the absence of comprehensive, cross-cutting examinations of climate change risks from a whole-of-government perspective.



Adapted with permission from GC (2014)

Figure 1.1

Negative Climate Change Impacts in Canada

Canada is experiencing a wide range of negative effects from climate change, which vary by region. This figure includes some illustrative examples.

1.1 THE CHARGE TO THE PANEL

In this context, the Treasury Board of Canada Secretariat (the Sponsor) asked the Council of Canadian Academies (CCA) to convene an expert panel to answer the following questions:

What are the top climate change risks facing both Canada and the federal government and their relative significance, and which have the most potential to be minimized by adaptation measures?

> *What criteria should be used to assess the relative impact of the risks from a changing climate (e.g., lives affected, cost, impact on economic activity, degree or rate of change, reversibility)?*
>
> *How should the risks be categorized in order to support effective decision making and action (e.g., more action needed, research priority, sustain current action, watching brief)?*

The CCA convened a panel of experts with diverse disciplinary backgrounds, knowledge of climate change adaptation, and experience in assessing and responding to climate risks in Canada and internationally. The Expert Panel on Climate Change Risks and Adaptation Potential (the Panel) was asked to consider the top climate risks facing Canada at the national level, the significance of these risks to the federal government, and its roles and responsibilities for managing these risks and supporting climate change adaptation in Canada. The Panel met eight times over the course of 2018 and 2019 (twice in person and six times by videoconference) to review evidence and deliberate on its charge. A workshop was also held to gather evidence and insight from a wider group of experts.

This report presents the Panel's main findings and conclusions at the culmination of this process. As with all CCA reports, it was subjected to a comprehensive peer review prior to its finalization and public release. The Sponsor met with the Panel at the outset of the assessment to clarify the charge but did not engage further with the Panel in order to preserve the independence of the process.

1.2 THE PANEL'S APPROACH

The Panel's conclusions about the climate risks facing Canada are grounded in its collective judgment based on available evidence and members' knowledge arising from their own areas of research and expertise. The Panel's use of expert judgment grounded in a review of the scientific evidence is consistent with climate change risk assessments undertaken elsewhere (e.g., Gov. of Japan, 2015; King *et al.*, 2015; ASC, 2016; EEA, 2018; WEF, 2018) and with current approaches to national risk assessment (OECD, 2017); expert judgment was fundamental given gaps in the evidence and uncertainties associated with longer-term forecasts of climate change and related risks.

A detailed description of the Panel's risk assessment methods and their limitations is provided in the Appendix. In designing its process, the Panel reviewed Canadian initiatives, and sought to learn from the experiences of other jurisdictions that have undertaken national or regional assessments of climate risk. Initiatives in other jurisdictions examined by the Panel included the recent national climate risk assessments undertaken in the United Kingdom (ASC, 2016), the U.S. Government Accountability Office's review of high risks facing the United States federal government (GAO, 2017), the fourth U.S. National Climate Assessment (USGCRP, 2018), and climate risk assessments and adaptation studies from Australia (AGO, 2006), Japan (Gov. of Japan, 2015), Germany (Gov. of Germany, 2015), and other European countries (EEA, 2018). While the Panel was informed by its understanding of the strengths and weaknesses of these initiatives, it did not seek to replicate them. This project's approach was tailored to the interests of the Sponsor and the nature of the assessment process, which included an expert workshop, reliance on a Panel composed of a small group of experts, and expedited evidence-gathering and assessment.

1.2.1 Sources of Evidence

The Panel considered several sources of evidence. Existing literature reviews and syntheses of the scientific evidence were prioritized due to the nature of the assessment. Synthesis reports from Natural Resources Canada (Lemmen *et al.*, 2008; Warren & Lemmen, 2014b), the National Round Table on the Environment and the Economy (NRT, 2010), and the Intergovernmental Panel on Climate Change (IPCC) (Romero-Lankao *et al.*, 2014) were key sources of evidence as they provide comprehensive reviews of climate change impacts facing Canada and North America. These reviews were supplemented by additional studies and more recent research to the extent possible. The Panel did not commission new evidence or studies, and it had a limited ability to canvass the large amount of relevant scientific information published on an ongoing basis given the time and resources available.

Limited Use of Indigenous Knowledge

The Panel recognized that Indigenous knowledge is an important source of evidence on climate change impacts and adaptation in Canada. As noted by Cunsolo and Hudson (2018), "Indigenous Peoples have been actively participating in research, observing and monitoring changes upon their lands, making decisions based on evidence and lived experiences, and adapting [to environmental changes] for generations." The value of this type of knowledge is now widely acknowledged in the international and Canadian climate change research communities (IPCC, 2014a; Warren & Lemmen, 2014b). However, mainstream reviews of climate science still struggle to access and incorporate Indigenous knowledge (Ford *et al.*, 2016b). References to Indigenous people and knowledge increased significantly in the IPCC's latest assessment, but coverage of Indigenous issues remained mostly general, limited in scope, and showed little critical engagement with Indigenous knowledge systems (Ford *et al.*, 2016b). Indigenous knowledge is frequently used to inform discussions of historical climate baselines and norms (particularly with respect to discussions of human vulnerability and impacts), but is also often "treated as a static form of knowledge being undermined or made irrelevant by climate change" (Ford *et al.*, 2016b), thereby failing to appreciate the dynamic and evolving nature of these knowledge systems.

Furthermore, it has been recognized by experts that Indigenous knowledge, when extracted from its context (i.e., relationships, world views, values, cultures, processes, and spirituality that give it meaning), is in danger of misuse and misappropriation when integrated into scientific frameworks (Simpson, 2001; Huntington, 2013). Simpson (2001) points out that scientists tend to be specifically interested in Indigenous knowledge that addresses ecological issues while Indigenous Peoples do not want others deciding which aspects of Indigenous knowledge are important and which are to be ignored. This is echoed by Whyte (2017), who states that, "[w]hile Indigenous knowledges obviously have useful information about the nature of ecological changes, it is perhaps more interesting to explore how renewing Indigenous knowledges serves the motivation of people and communities to address climate change."

While Indigenous knowledge is reflected in the syntheses examined by the Panel to a limited extent, its inclusion often suffers from deficiencies such as those noted above. The Panel also did not have any Indigenous members, and only one Indigenous person participated in the workshop. It therefore lacked access to Indigenous perspectives and knowledge held and passed on through oral, local, and place-based traditions by Elders and other Indigenous experts.

Inuit Tapiriit Kanatami, Assembly of First Nations, and Métis National Council have documented their expectations for what constitutes an acceptable level of engagement in climate assessments and similar activities (AFN, 2018; ITK, 2016; MNC, 2016; Trudeau & Bellegarde, 2016). Future climate risk assessments would benefit from a comprehensive and inclusive process, potentially co-designed by and co-executed with Indigenous participants, one that is better able to incorporate Indigenous knowledge and perspectives.

1.2.2 The Role of the Expert Workshop

As part of the evidence-gathering process for this project, the Panel organized an expert workshop in October 2018, which brought together an additional 17 climate change and adaptation experts from across Canada and the United States. Participants from various sectors and academic disciplines were selected to assess the climate risks facing Canada and the federal government. Analysis, discussion, and debate were aided by a facilitator using a unique group decision support software platform that allows for rapid idea generation and consensus building. This process aided in gathering evidence from a wide group of experts and in synthesizing insights on the relative severity of climate risks and Canada's ability to adapt to these threats. Many of the Panel's conclusions stem from insights shared during this event.

1.2.3 Scoping Decisions

The Sponsor emphasized prioritizing horizontal risks that cross multiple federal departments, disciplines, sectors, and systems. The Panel was instructed not to spend extensive time identifying or characterizing the risks, and instead to rely on existing publications. Actions and policies related to emissions reductions were excluded from the scope given the focus on risk assessment and adaptation. Following discussion, the Panel confirmed several additional scoping decisions related to the project, including its national focus, the adoption of a 20-year time period, and the exclusion of climate change opportunities from its assessment.

National Focus

The Panel considered Canada's climate change risks from a national perspective. Some climate risks are regionally or locally significant, and can be adequately addressed at those levels, while others require national attention or assistance. Regional impacts that may be of national significance are included in this report.[1] For example, Canada's three northern territories account for nearly 40% of Canada's land mass (NRCan, 2017). This, combined with Canada's status as an Arctic nation and the centrality of Arctic issues and sovereignty to national and international affairs, elevates the risks to Arctic areas to the national level. Similarly, the Panel considered risks to coastal communities, given that Canada has over 243,000 km of coastline (more than any other country) populated by about 6.5 million people (Lemmen *et al.*, 2016). The potential impacts of climate change in coastal regions were also considered of national significance as they could affect Canada's economy as a whole, and have potential implications for property values, defence, and international trade. Given the national focus, however, the assessment did not specifically address local- or community-level climate risks.

Twenty-Year Period

Some climate change impacts, such as flooding and the increasing frequency and severity of wildfires, have already resulted in major impacts on ecological, economic, and social systems in Canada (Warren & Lemmen, 2014a; Feltmate, 2018). Others are only now emerging, or will emerge in the future as the climate changes. The Panel focused primarily on climate risks facing Canada over the next 20 years (i.e., 2020 to 2040). This time period is consistent with the objectives of the Sponsor, and can inform shorter-term policy and funding decisions related to federal climate adaptation priorities. Focusing on this period also has the advantage of reducing uncertainty related to the extent and pace of climate change. Much of the warming and associated changes that will occur over this period are a result of GHG emissions already released into the atmosphere, and current projections suggest continued warming in Canada and globally over the coming decades regardless of the trajectory of global emissions (GC, 2018a). Longer-term climate projections (and associated risk assessments) are subject to greater uncertainty given the wide range of possible emissions pathways and the inherent complexity of climate dynamics.

1. See Lemmen *et al.* (2008) for a review of climate change impacts in Canada with a regional focus.

However, some risks arising over the long term may require adaptation actions soon due to the involvement of relatively long-lived infrastructure or assets. As a result, the Panel and workshop participants also made efforts to consider and highlight potentially significant, longer-term climate risks where relevant to adaptation needs and priorities in the next 20 years.

Exclusion of Climate Change Opportunities

Climate change will create opportunities, as well as risks, for Canada. For example, warmer temperatures, longer growing seasons, and increased atmospheric concentrations of carbon dioxide could benefit the agricultural sector, allowing some higher-value crops to be grown further north (Campbell *et al.*, 2014; Porter *et al.*, 2014). Warmer winter temperatures could also decrease the incidence of cold-related mortality in Canada (Goldberg *et al.*, 2011; Berry *et al.*, 2014), and decreasing Arctic sea ice may allow increased marine shipping through the Northwest Passage leading to new economic benefits for northern communities (Dawson *et al.*, 2016). Such opportunities are sometimes analyzed concurrently with climate risks in national assessments (e.g., May *et al.*, 2018); however, in the Panel's view, a concurrent analysis of risks and opportunities is outside the scope of this assessment, which is intended to identify the top climate risks facing Canada (Chapter 2) and those with the highest adaptation potential (Chapter 3). Furthermore, the criteria suited to analyzing opportunities versus risks are sometimes different, as are the implications for adaptation action and planning.

1.2.4 Future GHG Emissions Trajectories and the Role of Mitigation

Assessing risks requires making predictions about the future based on the best information available. Though there is considerable uncertainty about how climate change will manifest at regional and local scales, the main source of uncertainty about the global extent of climate change is the trajectory of future GHG emissions. This will depend on policy decisions related to emissions mitigation, as well as on how underlying drivers such as population, economic growth, land use, and technology evolve in the coming decades. The current emissions trajectory is consistent with the upper range of modelling projections, suggesting global average temperature increases could be in the range of 3.2 to 5.4°C by 2100.[2] As noted in the most recent IPCC report, even a warming of 1.5°C will result in disruptive and costly impacts on natural and human systems, while a warming of 2°C amplifies many threats, increasing their magnitude and costs (IPCC, 2018). Shifting to a lower global emissions trajectory with correspondingly lower risks will require aggressive mitigation policies in the near term on the part of all countries — especially major emitters. Only in scenarios where Canada and other countries reduce carbon emissions to near zero early in the second half of the 21st century will more limited warming occur (Bush & Lemmen, 2019). Reducing global emissions is therefore essential for minimizing climate change risks over the long term.

The Panel's assessment of climate risks is based on expected changes to Canada's climate system in the coming decades. In the period between 2016 and 2036, most of Canada is expected to experience a warming of between 0.5 and 1.5°C above the 1986–2005 average in a lower-emission scenario, and between 1.0 and 2.0°C for most of the country in a higher-emission scenario (GC, 2018a).[3] Because the Panel focused on risks facing Canada over the medium term (i.e., 2020 to 2040), and because emissions scenarios project broadly similar levels of warming during this period (Bush & Lemmen, 2019), its assessment of Canada's climate risks is consistent with a wide range of emissions pathways and associated changes in the climate.

1.2.5 Projected Changes in Canada's Climate

Studies have documented ongoing changes in Canada's climate (Lemmen *et al.*, 2008; Warren & Lemmen, 2014b; Bush & Lemmen, 2019), and the expected warming over the next 20-year period will continue to lead to impacts on many geophysical, biological, and socio-economic systems. Table 1.1 summarizes projected climate changes in Canada, which informed the Panel's risk assessment presented in Chapter 2.

2. Much of the research in this area over the past decade has used the Representative Concentration Pathway (RCP) scenarios featured in the IPCC's fifth assessment (IPCC, 2014a).
3. According to Bush *et al.* (2019), projections indicate Canada will warm by an additional 1.5°C in a low-emission scenario between 2031 and 2050, and 2.3°C for the same period in a high-emission scenario.

Table 1.1

Projected Changes in Canada's Climate

Temperature	
Seasonal temperature	The largest increases in air temperature are projected for northern Canada in winter. In summer, the largest increases are projected for southern Canada and the central interior. The magnitude of projected warming varies substantially by emission scenario.
Extremes in daily temperature	Increases in the frequency and magnitude of unusually warm days and nights, and decreases in unusually cold days and nights, are projected to occur throughout the 21^{st} century.
Long-duration hot events	The length, frequency, and/or intensity of warm spells, including heatwaves, are projected to increase over most land areas.
Rare hot extremes	Rare hot extremes are projected to become more frequent. For example, a 1-in-20 year extreme hot day is projected to become about a 1-in-5 year event over most of Canada by mid-century.
Precipitation and Other Hydrological Indicators	
Seasonal precipitation	Increases in precipitation are projected for the majority of the country and for all seasons, with the exception of parts of southern Canada, where a decline in precipitation in summer and fall is projected.
Heavy precipitation	More frequent heavy precipitation events are projected, with an associated increased risk of flooding.
Rare precipitation events	Rare extreme precipitation events are currently projected to become about twice as frequent by mid-century over most of Canada.
Streamflow	Increases in winter streamflow are projected for many regions in southern Canada. Mean annual streamflow is projected to decrease in some regions of Alberta and Saskatchewan, while projections for other regions vary across different scenarios.
Snow Cover	
Snow-cover duration	Widespread decreases in the duration of snow and ice cover are projected across the Northern Hemisphere, with the largest changes in maritime mountain regions, such as the west coast of North America.
Snow depth	Maximum snow accumulation over northern high latitudes is projected to increase in response to projected increases in cold-season precipitation.
Permafrost	
Ground temperature	Warming of the permafrost is projected to continue at rates surpassing those observed in records to date. Because much of the Arctic permafrost has a low average temperature, it will take many decades to centuries for colder permafrost to completely thaw.
Sea Level	
Global sea-level rise to 2100	Estimates of the magnitude of future changes in global sea level by the year 2100 range from a few tens of centimetres to more than a metre.
Global sea-level rise beyond 2100	Projections beyond 2100 indicate continuing global sea-level rise over the coming centuries and millennia. Global sea-level rise may eventually amount to several metres.
Relative sea-level change	Patterns of change along Canadian coastlines will continue to be influenced by land uplift and subsidence as well as by changes in the oceans. Sea-level rise will continue to be enhanced in regions where the land is subsiding, and sea level is likely to continue to fall in regions where the land is rapidly rising. Regions where the land is slowly rising may experience a transition from sea-level fall to sea-level rise.
Sea-Ice Extent	
Arctic summer sea ice	A nearly ice-free summer is considered a strong possibility for the Arctic Ocean by mid-century, although summer sea ice may persist longer in the Canadian Arctic Archipelago region.
Lake Ice	
Ice-cover duration	With the continued advance of ice cover break-up dates and delays in ice-cover freeze up, ice-cover duration is expected to decrease by up to a month by mid-century.

Adapted from Warren and Lemmen (2014a)

Note: Examples of projected changes in Canada's climate are derived from ensembles of global climate models. In general, the magnitude of the stated changes will increase under higher emission scenarios.

1.3 REPORT STRUCTURE

The remainder of this report is structured as follows:

- **Chapter 2** identifies and discusses the top climate change risks facing Canada based on the Panel's assessment.
- **Chapter 3** assesses the adaptation potential associated with these risks, in terms of the extent to which damage can be reduced or eliminated through adaptation measures.
- **Chapter 4** discusses how federal adaptation planning can be served by categorizing and prioritizing the nature of federal involvement for each identified area of climate change risk.
- **Chapter 5** summarizes the evidence and offers the Panel's final reflections on its charge and on the importance of taking action to manage climate change risks.

2

Top Climate Change Risks Facing Canada

KEY FINDINGS

- The Panel identified 12 major areas of climate change risk facing Canada at a national level: agriculture and food; coastal communities; ecosystems; fisheries; forestry; geopolitical dynamics; governance and capacity; human health and wellness; Indigenous ways of life; northern communities; physical infrastructure; and water. All 12 risk areas could lead to significant losses, damages, or disruptions over a 20-year timeframe.
- Of these, the top six risk areas are physical infrastructure, coastal communities, northern communities, human health and wellness, ecosystems, and fisheries.
- Climate change poses significant risks for Canadian businesses and the economy as a whole.
- The 12 areas of climate change risk are interconnected, creating the potential for cascading effects and making it difficult to anticipate how impacts will propagate throughout natural and human systems.

Changes in Canada's climate are expected to result in widespread disruption and harm in the coming decades, affecting both natural and human systems. Rapid shifts in climate and environmental conditions may exceed the pace at which Canada's ecosystems and species are able to adapt, impairing their functioning and viability, especially when opportunities for migration or other adaptive responses are limited. Future climate conditions may exceed the design specifications reflected in building codes, engineering standards, and other measures, and increase the likelihood of critical damage and infrastructure failures. Extreme weather events may create widespread disruptions, and impose a series of economic and social costs on individuals, communities, governments, and businesses. New risks are arising from the melting of Arctic sea ice, sea-level rise, ocean acidification, and the spread of vector-borne disease. This chapter reviews the climate risks facing Canada, and identifies the top areas of risk, based on their potential consequences and likelihood of causing significant damages, disruptions, or harm.

2.1 UNDERSTANDING RISK IN THE CONTEXT OF CLIMATE CHANGE

Climate change risks result from the interaction of vulnerability, exposure, and hazard.

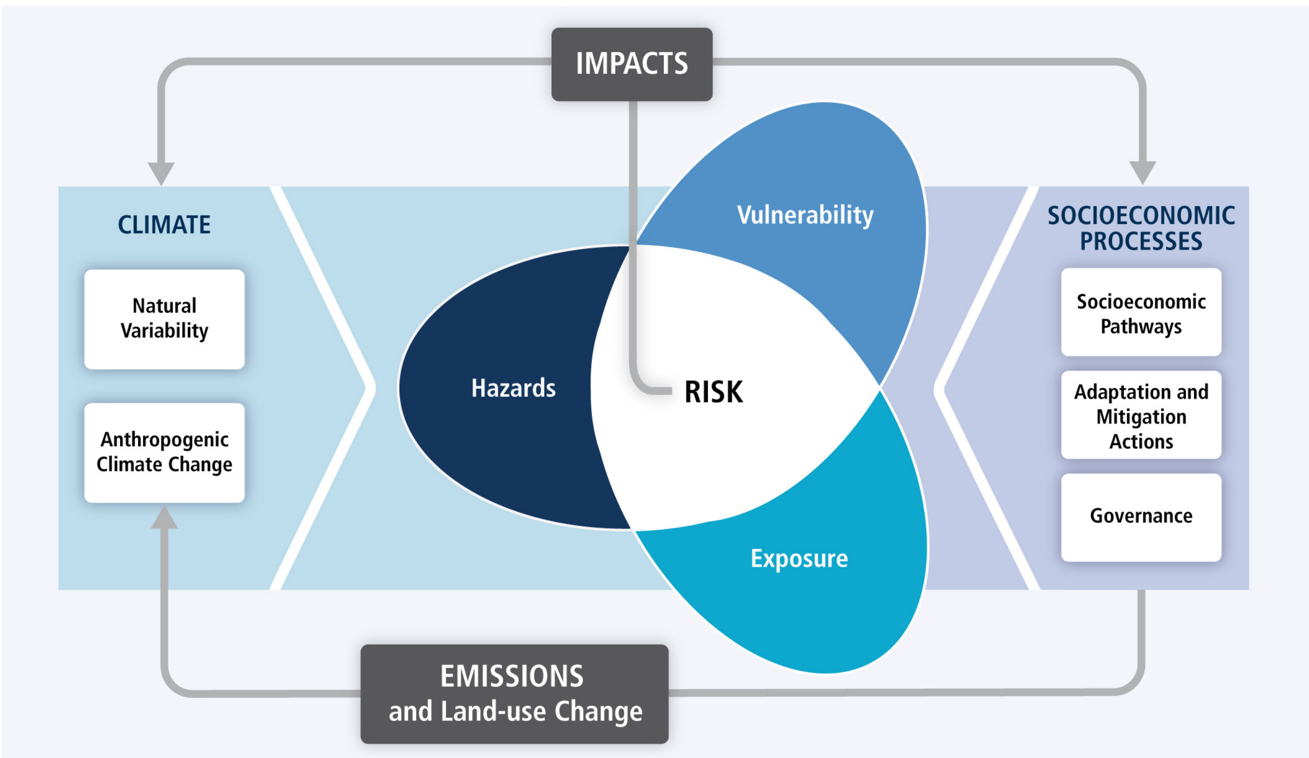
Terms such as *risk*, *adaptation*, *adaptive capacity*, *vulnerability*, *resilience*, and *exposure* are interrelated and have been applied in multiple ways (and at multiple scales) in climate change research (Smit & Wandel, 2006). Climate change *risks* are usually perceived to emerge from interactions among climate-related hazards and factors that determine the susceptibility of human and natural systems to harm (vulnerability and exposure).[4] The Panel adopted the same approach as the IPCC (Figure 2.1), in which risk is understood as:

> [t]he potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.
>
> (Oppenheimer *et al.*, 2014)

4. Definitions for *vulnerability*, *exposure*, and *hazard* are included in the Glossary at the end of this report.

Hazards arise from the climate system, and result from natural climate variability as well as change caused by human action. Many of the climate-related hazards expected in Canada are captured in the projections in Table 1.1. These include increased incidences of heatwaves, droughts, heavy precipitation events, rising sea levels, changing snow and ice conditions, and changes in streamflow.

Exposure is associated with the presence of people, livelihoods, species, ecosystems, and other systems in settings that could be adversely affected (e.g., buildings or communities in areas prone to flooding). Canada has a unique geographic, environmental, and social identity that shapes the hazards that it faces and its exposure to climate-related risks. For example, as one of the most heavily glaciated countries in the world, with vast freshwater resources and the fourth-largest installed hydropower capacity (IHA, 2018), Canada is susceptible to risks from changes in precipitation patterns and the timing and volume of spring and glacial runoff. In addition, nearly half of Canada's land area is covered by forest, leading to a substantial economic reliance on forest-based resources and susceptibility to disturbances in forest ecology and wildfire outbreaks. Compared to smaller, more geographically homogenous countries, Canada is affected by a wider range of climate change impacts. Political and economic characteristics affect Canada's exposure to systemic, cross-border risks.



Reproduced with permission from IPCC (2014b)

Figure 2.1

Climate Change Risk as a Function of Vulnerability, Exposure, and Hazard

Illustration of the core concepts of the Working Group on Impacts, Adaptation, and Vulnerability from the IPCC's Fifth Assessment Report (Figure SPM.1). Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socio-economic processes including adaptation and mitigation (right) are drivers of hazards, exposure, and vulnerability.

Vulnerability reflects "sensitivity or susceptibility to harm and a lack of capacity to cope and adapt" (Oppenheimer *et al.*, 2014). People's vulnerability to specific risks varies based on their degree of dependency, health, and income, and differs among individuals within a community. As noted by the IPCC:

> People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are especially vulnerable to climate change… This heightened vulnerability is rarely due to a single cause. Rather, it is the product of intersecting social processes that result in inequalities in socioeconomic status and income, as well as in exposure. Such social processes include, for example, discrimination on the basis of gender, class, ethnicity, age, and (dis)ability.
>
> (Oppenheimer *et al.*, 2014)

The historical traumas experienced by Indigenous Peoples due to colonialism, loss of traditional lands, and loss of ways of life have led to physical and mental health impacts, which in turn increase Indigenous Peoples' vulnerability to climate change impacts (Jantarasami *et al.*, 2018). The Public Health Agency of Canada has highlighted how colonialism and intergenerational trauma contribute to health inequities between Indigenous and non-Indigenous populations in Canada (PHAC, 2018). Indigenous Peoples' vulnerability to climate change is intensified by environmental changes caused by colonialism (Whyte, 2017).

Conversely, other factors moderate and reduce vulnerability. At the national scale, a comparatively stable macroeconomic environment, a broad social safety net, an open and pluralistic society, and a tradition of responsible public-sector governance all enhance Canada's ability to manage many climate risks. Measures of governance quality, in particular, have been found to be highly predictive of national adaptation capacity (Berrang-Ford *et al.*, 2014). In the Panel's view, geographic and ecological diversity also contribute to resilience[5] at a national level given that relatively few climate risks will affect the entire country at the same time, though combined, simultaneous, or consecutive impacts from multiple hazards could challenge this resilience.

2.1.1 Risk Identification

The Panel identified 12 major areas of climate change risk facing Canada.

Based on workshop discussions, existing reviews of climate change impacts on Canada (NRT, 2010; Warren & Lemmen, 2014b) and North America (Romero-Lankao *et al.*, 2014), and its own deliberations, the Panel concluded that the majority of climate risks facing Canada could be grouped into 12 areas (Table 2.1). Risks were categorized based on *who* or *what* is at risk rather than by the climate hazards involved. This approach was favoured as it was seen to better support adaptation planning by capturing the potentially synergistic effects of multiple climate impacts on a particular area.

The Panel observed a degree of consistency and compatibility between the climate change risks identified by the Panel and those identified for the Assembly of First Nations by the Centre for Indigenous Environmental Resources: changes in water quality and quantity; increase in frequency and severity of extreme weather events; increase in frequency and severity of forest fires; changes in animal behaviour / loss of keystone species; and changes in snow and ice due to warmer weather (CIER, 2008).

2.1.2 Interconnectedness

Major climate change risks are complex and interconnected, and negative impacts can propagate through natural and human systems in ways difficult to anticipate.

Climate change risks are often interconnected. For instance, flooding from heavy rain and storm surges poses risks to infrastructure, which can in turn interfere with human health and wellness through disrupted access to health and social services, compromise water quality and availability through damage to water treatment and distribution systems, and challenge governance and capacity when existing systems fail to adequately manage an infrastructure disruption. Heatwaves represent a risk to individuals, especially vulnerable people, though the extent of that risk can be mediated by infrastructure and the services it provides (e.g., building design, air conditioning, healthcare systems) and the resilience of electricity grids when demand spikes. Impacts to the business and economic sector associated with flooding and heatwaves cut across these areas of risk.

5. The concept of resilience is closely tied to vulnerability. *Resilience* is defined by the IPCC as "[t]he capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation" (Agard *et al.*, 2014), building on the definition used by the Arctic Council (2013).

Table 2.1
Twelve Major Climate Change Risk Areas Facing Canada

Area of Climate Risk	Description
Agriculture and Food	Risks to agriculture and food systems, including adverse impacts on agricultural crops and the agricultural sector due to changing climate and environmental conditions, and increasing risk of disruptions to global food production and distribution systems.
Coastal Communities	Risks to coastal communities in Canada, including damage to coastal infrastructure, property, and people from inundation, saltwater intrusion, and coastal erosion due to sea-level rise and storm surges.
Ecosystems	Risks to Canadian ecosystems and species, including threats to biodiversity, ecosystem resilience, and the ability of ecosystems to provide a range of benefits to people such as environmental regulation, provision of natural resources, habitat, and access to culturally important activities and resources.
Fisheries	Risks to Canadian fisheries and fish stocks, including declining fish stocks and less productive/resilient fisheries due to changing marine and freshwater conditions, ocean acidification, invasive species, and pests.
Forestry	Risks to Canadian forestry, including declining forest health and lower production of timber and forest products due to changing weather patterns, increasing frequency of extreme weather events, increasing range of invasive species and/or pests, and growing prevalence of wildfires.
Geopolitical Dynamics	Risks related to geopolitical dynamics affecting Canada, including increased international migration and associated political, social, and economic stresses; increasing political and social conflict over climate-affected resources; heightened geopolitical tensions over Arctic sovereignty and resources; and increasing need for humanitarian assistance and foreign aid due to climate-related crises.
Governance and Capacity	Risks related to the capacity of Canadian governments to effectively provide public services, manage and respond to climate risks, and maintain the public's trust, including new or increased obligations on government policies, programs, and budgets.
Human Health and Wellness	Risks to human health and wellness in Canada, including adverse impacts on physical and mental health due to hazards such as extreme weather events, heatwaves, lower ambient air quality, and increasing ranges of vector-borne pathogens.
Indigenous Ways of Life	Risks to Indigenous ways of life in Canada, including declining opportunities for practising activities such as hunting, fishing, and foraging; and associated impacts on safety, food security, communities, Indigenous knowledge, language, and culture.
Northern Communities	Risks to northern communities and people in Canada, including damage to buildings, roads, pipelines, power lines, and airstrips due to thawing permafrost; reduced or disrupted access to communities and facilities due to warmer temperatures; and increased risks from marine accidents due to increased marine traffic and reduced summer sea-ice extent.
Physical Infrastructure	Risks to physical infrastructure in Canada (e.g., homes, buildings, roads, bridges), including damage from extreme weather events such as heavy precipitation, high winds, and flooding; increased probability of power outages and grid failures; and an increasing risk of cascading infrastructure failures.
Water	Risks to Canadian water systems and water supply, including reduced water quality and declining or less regular water supply for communities, industry, and utilities due to changing precipitation patterns, melting glaciers, and diminishing snowpack, and earlier or more variable spring runoff.

Degradation of ecosystems and loss of biodiversity can have cascading impacts on the natural and human systems that depend on them, many of which may not be well understood. As described in the 2018 U.S. National Climate Assessment:

> The world we live in is a web of natural, built, and social systems — from global and regional climate; to the electric grid; to water management systems such as dams, rivers, and canals; to managed and unmanaged forests; and to financial and economic systems. Climate affects many of these systems individually, but they also affect one another, and often in ways that are hard to predict.
>
> (Clarke, 2018)

Figure 2.2 highlights some of the interconnections among the 12 main areas of risk identified by the Panel. As a result of these interconnections, the consequences in one domain often have implications in others. The Panel observed a hierarchy wherein impacts on ecosystems and physical infrastructure can affect natural resource industries, water supplies, food and agriculture production, business and economic well-being, and human health and wellness. Likewise, water and ecosystem health are inextricably linked to each other, to food and energy availability, and to the functioning of many human systems such as Indigenous ways of life. Indigenous ways of life are also practised in many northern communities, as well as in some coastal communities. Risks associated with governance failure underlie all of these areas and can exacerbate adverse impacts.

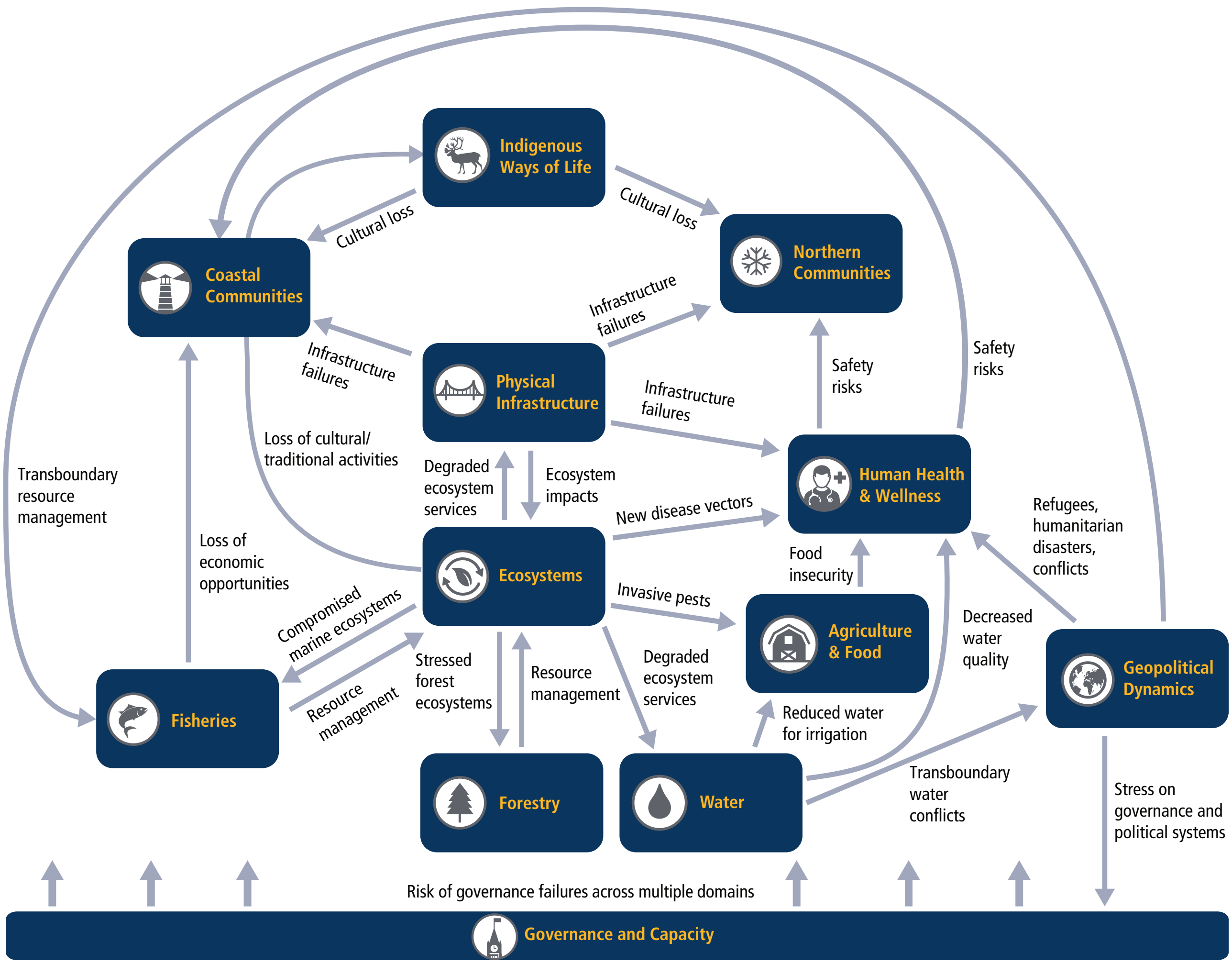


Figure 2.2

Interconnections Among Areas of Climate Change Risk

Climate-related risks are often interconnected through a dense web of causal relations. Note that the connections shown are illustrative and not exhaustive of all possible connections.

These interdependencies also argue for additional caution; estimates of risk may fail to adequately appreciate cascading effects. The latest U.K. climate risk assessment notes that "the true magnitude of risks and opportunities may be underestimated because each tends to be considered in isolation but in practice will act in combination" (ASC, 2016). Risk assessments are more accurate and useful when they incorporate information on the potentially synergistic effects of climate risks. Improving our understanding of these interconnections and their potential implications is therefore an important research challenge (Clarke *et al.*, 2018). Risk assessments should take these interdependencies into account as they characterize uncertainty levels and analyze sensitivity of results to changes in climate conditions. The same is true for adaptation assessments, as such interconnections can hinder or enhance adaptation efforts by creating complementarities, synergies and co-benefits, or conflicts (Section 3.3.1).

2.2 RISK ASSESSMENT APPROACH AND OVERALL RESULTS

Standard risk assessments use two main criteria for analysis: the *consequences* (or magnitude) of a potential impact, and its *likelihood* of occurrence (OECD, 2017; WEF, 2018). Through discussions at the workshop, Panel deliberations, and reviews of criteria applied in other jurisdictions and contexts (e.g., Gov. of Japan, 2015; UN, 2015; Warren *et al.*, 2016), the Panel identified five main criteria for assessing the relative consequences of the risks from a changing climate: (i) impacts on the environment and natural systems; (ii) impacts on the economy; (iii) impacts on society and culture; (iv) impacts on human health and wellness; and (v) impacts on geopolitical dynamics and governance. The Panel also noted calls for applying a gender lens and a human rights lens to climate change (e.g., Eyzaguirre, 2009; OHCHR, 2010; Griffin Cohen, 2017; OHCHR, n.d.), and sought to bear these considerations in mind across all areas of risk and across all five criteria where appropriate.

The Panel's effort produced a high-level identification of the top risks facing Canada. Future climate risk assessments for Canada would benefit from a structured evaluation of each risk relative to each of the five criteria (e.g., through a formal multi-criteria decision analysis). However, variation in the extent and quality of evidence and uncertainty surrounding these impacts currently limit the feasibility of such an approach. The Panel was not able to carry out such an evaluation within the constraints of its project. However, Panel members did individually factor in impacts across these five areas in their overall assessment of the consequences of the climate risks facing Canada, based on members' understanding of the evidence, and insights shared at the workshop.

Figure 2.3 shows the Panel's assessment of the 12 major areas of climate risk facing Canada based on the expected consequences and their likelihood of occurrence over the next 20 years. Indigenous ways of life are considered an important area of risk, but, given the lack of Indigenous Panel members and only limited inclusion of Indigenous knowledge in the assessment, the Panel was less confident in its rating of the risks in this area. Both risk assessment criteria are plotted on a scale of 0 to 100 in Figure 2.3. For *consequences*, a score of 0 implies "minimal" consequences whereas 100 implies "catastrophic" consequences. For *likelihood*, a score of 0 implies there is no chance that risks in that area would cause significant disruptions, damages, or losses in the next 20 years nationally, whereas a score of 100 implies a certainty of significant disruptions, damages, or losses. Note that this assessment takes into account both current conditions and anticipated autonomous or planned adaptation.

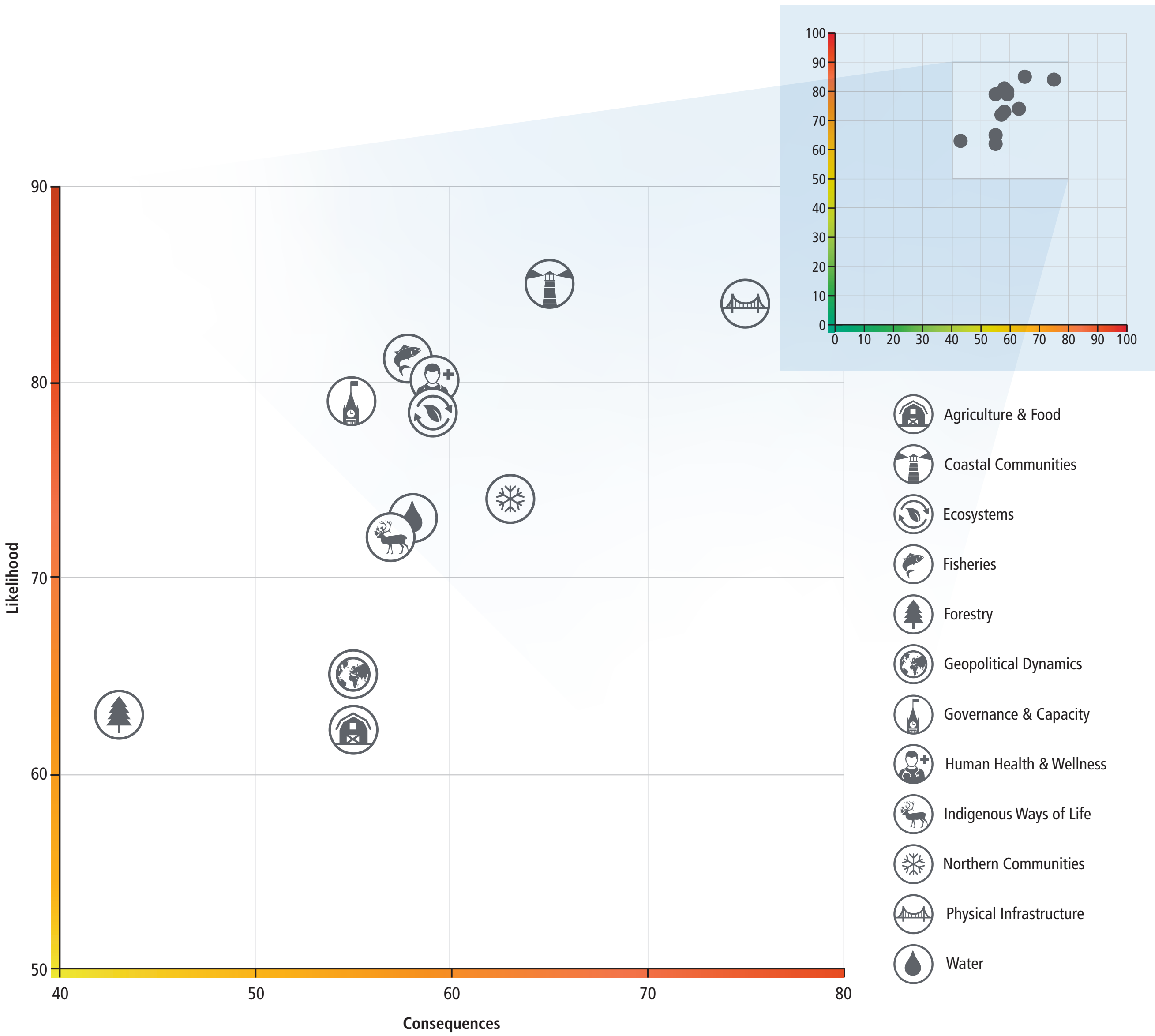


Figure 2.3

Panel Assessment of Consequences and Likelihood for Major Areas of Climate Change Risk

This figure represents the Panel's assessment of consequences (disruptions, damages, or losses in the next 20 years) and likelihood for major climate risk areas facing Canada. The smaller graph shows the ascribed results using the entire 0–100 scale for each axis, and the main graph provides a detailed view showing the relative positioning of these risks. The Panel was less confident in its relative rating of the Indigenous ways of life risk area, as there were no Indigenous members on the Panel and only limited inclusion of Indigenous knowledge in the assessment.

All major areas of climate change risk facing Canada are nationally significant and could lead to significant losses, damages, or disruptions over the next 20 years. At the national level, climate change risks in the next 20 years are highest in the areas of physical infrastructure, coastal communities, northern communities, human health and wellness, ecosystems, and fisheries.

The consequences associated with each of these areas of climate risk are high on a 20-year timescale and would be greater over the longer term. In the Panel's view, the likelihood of significant damages, losses, or disruptions is in excess of 50% for all risk areas and above 70% for more than half of the risk areas. As indicated by their relatively tight grouping within the small graph of Figure 2.3, the overall level of risk across these areas is broadly similar. To a degree, this tight grouping is also related to the interdependencies among risks discussed in Section 2.1.2. In the absence of major GHG emissions mitigation on a global level, the degree of climate warming and associated impacts will increase in subsequent years, and more comprehensive risk assessments will be needed to inform additional adaptation responses.

Evidence limitations and considerable uncertainty are associated with many of the major climate risk areas facing Canada. Taking these into account, when the Panel considered risk areas from a national perspective, the highest levels of climate risk facing Canada over the next 20 years are associated with physical infrastructure, coastal communities, northern communities, human health and wellness, ecosystems, and fisheries. In singling out these six areas, the Panel does not wish to downplay the other areas of concern, nor does it wish to dismiss the potential for the emergence of new or cascading risks.

Urban areas face a complex and interdependent set of risks arising from climate change.

More than 80% of people in Canada live in urban areas (StatCan, 2018), meaning that climate risks affect most people through their impacts on cities. These risks include extreme rainfall resulting in urban flooding, heatwaves, wildfires entering urban areas, and coastal infrastructure failing during storm-surge events. The concentration of complex and interconnected infrastructure in and around cities may amplify vulnerability (Dawson *et al.*, 2018b; Maxwell, 2018). At the same time, cities are highly interdependent with surrounding rural areas as well as broader national and global flows of goods and services including food, energy, and labour (Hunt & Watkiss, 2011).

Several features of the urban landscape can heighten the risks of climate change in urban areas. The density of the built environment contributes to the urban heat-island effect, which intensifies heatwaves and limits the extent to which night-time cooling occurs (Smith & Levermore, 2008; IPCC, 2018). This heightens the risks of adverse health impacts, particularly for vulnerable populations. During Montréal's 2018 heatwave, older people living alone and people with existing health problems were more adversely affected (CIUSSS, 2018). Extreme heat also increases demand for healthcare services in cities. The 2010 heatwave in Quebec, for example, led to approximately 3,400 additional emergency department admissions than would otherwise have occurred (Bustinza *et al.*, 2013).

Urbanization can also increase flood risk. The concentration of non-porous surfaces such as asphalt limits the ability of the ground to absorb water, and urban environments can increase total rainfall during storms by affecting the paths and dynamics of storm clouds (Zhang *et al.*, 2018). Again, the most vulnerable urban residents are at the greatest risk. Hurricane Sandy, for example, led to the evacuation of five hospitals and roughly 30 nursing homes and residential care facilities in New York City (Gibbs & Holloway, 2013). Hurricane Katrina in New Orleans illustrated the compounding influence of socio-economic factors as drivers of vulnerability. The capacity of indigent people to follow evacuation orders issued before the storm, for example, was often constrained by the lack of any practical means of leaving the city (Curtis *et al.*, 2007).

Climate change poses significant risks to Canadian businesses and the economy as a whole.

The costs of climate change are expected to be significant for Canada, affecting individuals, businesses, and governments, but the understanding of these costs is limited. A 2011 study put those potential costs between $21 and $43 billion per year by mid-century, depending on emissions trajectories and economic and population growth (NRT, 2011). In contrast, a recent review of the social cost of carbon across countries found that, in the near term, there could be economic benefits for countries such as Canada "because their current temperatures are below the economic optimum," but that in the long run the costs for Canada could be among the highest (Ricke *et al.*, 2018). Climate change costs are already being incurred today, as evidenced by significant increases in payouts from public and private insurance schemes. The Government of Canada's Disaster Financial Assistance Arrangements program (which reimburses the provinces/territories and individuals for expenses and damages resulting from disasters) experienced higher expenditures between 2009–10 and 2014–15 than in the previous 39 years combined, dating back to the program's inception in 1970 (CESD, 2016). Insured losses associated with extreme weather events rose from an "average of $405 million per year between 1983 and 2008 to $1.8 billion per year between 2009 and 2017" (Feltmate, 2018). These costs are further amplified by the insurance gap: "for every dollar of insured losses borne by insurers in Canada, three to four dollars are borne by governments and home and business owners" (Moudrak *et al.*, 2018). For households and communities, extreme weather events can also affect employment. Following the 2016 Fort McMurray forest fires, a net 7.6 million hours of work was lost in the Fort McMurray area and across Alberta the number of Employment Insurance beneficiaries increased by 12.6%[6] (Bourbeau & Fields, 2017).

Climate change will impose direct and indirect costs on Canadian business. Canada's 2017 trade-to-GDP (gross domestic product) ratio[7] was 64%, well above the global average (World Bank, 2017), and supply chain disruptions brought about by extreme weather events, changing water levels along shipping routes such as the St. Lawrence River, and changing patterns of supply and demand abroad could interfere with trade flows and enhance the interdependencies among economic sectors (NRT, 2012; Romero-Lankao *et al.*, 2014; World Bank, 2017). The U.S.-based CVS Health pharmacy chain reported $57 million in losses associated with short-term closures of over 1,000 pharmacies during the 2017 hurricane season (Norton, 2019).

The Insurance Bureau of Canada identifies climate change and associated losses among major issues facing business insurance today, noting that business and supply chain disruptions are increasing along with severe weather (IBC, 2018). Following the Fort McMurray, Alberta wildfires, for instance, businesses filed roughly 5,000 insurance claims with a total value of approximately $1.4 billion (IBC, 2018). An analysis of 79 U.S. industries found that climate change could have material financial impacts on 72 of these, representing 93% of U.S. equities (SASB, 2016). Financial impacts could flow from factors including the physical effects of climate change, regulatory changes, and the low-carbon transition (SASB, 2016). In 2017, approximately 15% of companies listed in the S&P 500 index reported that weather-related events had an impact on earnings, and among the 4% of companies that went on to quantify this effect, the average effect was a 6% earnings loss (S&P Global Ratings, 2018).

The Panel echoed the findings of other reviews (e.g., Arent *et al.*, 2014; Eyzaguirre & Warren, 2014), noting that there are major gaps in understanding of the direct and indirect economic impacts of climate change in Canada and associated adaptation options. Further research in this area could improve the effectiveness of decision-making.

2.3 TOP SIX CLIMATE CHANGE RISK AREAS FACING CANADA

2.3.1 Risks to Physical Infrastructure

Climate change poses a range of threats to publicly and privately held physical infrastructure (e.g., buildings, transportation systems and facilities, power systems, water and sewer systems, healthcare facilities, information and telecommunication systems) and the services it provides. Specific threats to infrastructure systems include damage from flooding from extreme precipitation, high winds or ice storms, wildfires, power outages and grid failures associated with heatwaves and high demand for air conditioning, thawing permafrost, and cascading failures affecting multiple infrastructure systems. Damage to physical infrastructure can have knock-on effects for human health and wellness, as access to health services could be compromised by infrastructure failures and extreme weather events (Berry *et al.*, 2014).

The increasing frequency and severity of extreme weather events have already caused significant damages or disruptions to infrastructure such as ports, airports, and waterways in North America (Romero-Lankao *et al.*, 2014). The consequences of risks to infrastructure systems include short-term economic implications and long-term impacts on growth and productivity. Climate-related disasters in Canada — such as the Fort McMurray wildfire (2016) and flooding in Alberta (2013) and Quebec (2017) (Figure 2.4) — have resulted in billions of dollars in damages and

6. One-third of the increase came from Wood Buffalo, the census agglomeration that includes Fort McMurray.

7. Since trade is measured as the sum of exports and imports while GDP is a value-added measure, the two are not directly comparable. This ratio is provided to offer an indicator of the value of trade in terms of the percent of GDP it represents. This does not imply that trade is 64% of GDP.

insurance claims (IBC, 2017). In 2016 alone, the Canadian insurance industry paid 200,000 claims worth a record \$4.9 billion for property damage associated with weather-related events, including wildfire, flooding, and severe wind (IBC, 2017). The 2013 Alberta floods destroyed 1,000 km of roads and washed away hundreds of culverts and bridges; over 5 million hours of work were lost, leading to \$485 million in lost economic output by the private sector (Gov. of AB, 2013). The full economic impact of the flooding is projected to exceed \$6 billion (ECCC, 2017). Costs to governments arising from extreme weather are also increasing. Liabilities accruing to the federal Disaster Financial Assistance Arrangements program have regularly exceeded \$1 billion per year since 2010 (PBO, 2016). An analysis of the potential costs of climate change-induced lower water levels along the St. Lawrence River between the Quebec-Ontario border and Trois-Rivières estimated that for the 4,300 properties with water access in that area, the cost in reduced property values would be roughly \$72 million, representing 2% of the value of those properties by 2064 (Larrivée *et al.*, 2016).

Thawing permafrost also poses significant risks to infrastructure in northern Canada, and risks are only expected to increase in coming decades. In 2008, heavy rains and flooding in Pangnirtung, Nunavut resulted in significant thermal erosion of the banks of the Duval River, as well as landslides and surface cracks up to seven metres deep. This damaged two bridges and separated residents from essential services, at a cost of close to \$5 million (Lemmen *et al.*, 2016). The Duval River bridge was rendered unusable, resulting in the separation of community facilities, and the interruption of water and sewage service (Lamoureux *et al.*, 2015). In Ross River, Yukon, permafrost thaw-associated damage forced the temporary closure of the Ross River school in 2015 (Calmels *et al.*, 2016). Permafrost degradation has also played a role in contributing to infrastructure degradation at Iqaluit International Airport in Nunavut (Oldenborger & LeBlanc, 2015), where resulting runway damage has affected airport operations with socio-economic implications (CBC News, 2013). Risks to northern communities are discussed in Section 2.3.3.

Figure 2.4

Flooded Street in Gatineau, Quebec, 2017

The Ottawa River flooded homes in Gatineau, Quebec on May 10, 2017. This flooding event led to mandatory evacuations in Rigaud as well as Pontiac and Montréal, and flooded over 5,000 homes in Quebec (Perreax, 2018). Flooding is likely to be one of the most costly sources of climate-related infrastructure damage in Canada in the coming years (Moudrak *et al.*, 2018).

2.3.2 Risks to Coastal Communities

Canada has over 243,000 km of coastline (more than any other country) populated by about 6.5 million people (Lemmen *et al.*, 2016). Many coastal communities and areas stand to be affected by rising sea levels (Lemmen *et al.*, 2016). This creates immediate and longer-term risks pertaining to flooding and inundation, as well as risks associated with coastal erosion and saltwater intrusion. These risks are often amplified by interactions with coastal weather patterns, storms, and diminishing protection from coastal sea ice (Atkinson *et al.*, 2016; Lemmen *et al.*, 2016). While gradual sea-level rise increases the risk of inundation in coastal areas, the immediate cause of flooding in many cases is likely to be a significant storm surge, possibly in combination with a high tide (Atkinson *et al.*, 2016). The loss of coastal lands could result in population displacement and social disruptions, and could interfere with the right to housing (Berry *et al.*, 2014; OHCHR, n.d.).

In some coastal communities, flooding events could result in major damages or disruptions, economic costs, and injuries. In 2010, Hurricane Igor led to the isolation of roughly 90 communities, 22 community states of emergency, and costs of approximately $200 million in Newfoundland and Labrador (EC, 2013; Lemmen *et al.*, 2016) (Figure 2.5). By mid-century, sea-level rise and storm surges are expected to impose over $50 billion in present-value costs, representing between 0.39 and 0.80% of GDP (Withey *et al.*, 2016). The majority of these costs would be incurred in British Columbia (Withey *et al.*, 2016). Canada's 18 major ports handle over $400 billion in goods annually and are exposed to risks associated with sea-level rise and extreme weather events (ACPA, 2016; Lemmen *et al.*, 2016).

The Canadian Press / Andrew Vaughan

Figure 2.5

Hurricanes and Flooding in Coastal Communities in Atlantic Canada

Much of Canada's Atlantic coast (particularly in the southeast) is expected to experience higher increases in relative sea levels due to ongoing land subsidence (Savard *et al.*, 2016). This increases risks from flooding events in coastal communities, and associated damage caused by the interaction of higher sea levels, storm surges, high tides, and heavy precipitation. Above, Hurricane Igor led to river flooding that washed away the road through Trouty, Newfoundland and Labrador in 2010.

The extent to which sea level will rise in specific areas of Canada is uncertain, yet some sea-level rise is anticipated on portions of all coasts (Lemmen *et al.*, 2016).[8] The impact that sea-level rise will have on any area is based on factors such as the extent of coastal development, location of major infrastructure, population of coastal communities, and overall adaptive capacity (Romero-Lankao *et al.*, 2014). In Atlantic Canada, relative sea-level rise over the century is expected to exceed the global average (Bush & Lemmen, 2019). In some of these areas, "a 50-centimetre rise in sea-level would inundate causeways, bridges, some marine facilities (e.g., ports, harbours) and municipal infrastructure, with replacement value estimated at hundreds of millions of dollars" (NRT, 2010, citing Shaw *et al.*, 2001). On the Pacific coast, a 2001 analysis of the Fraser River delta found that 1,550 hectares of urban industrial land, 1,125 hectares of urban residential and commercial land, and 4,675 hectares of agricultural land were vulnerable to inundation by one-metre sea-level rise in the absence of protective structures (Yin, 2001). Close to 300,000 people in Richmond and Delta in Greater Vancouver live at or below sea level, protected by 127 km of dikes that were not designed to accommodate sea-level rise (NRT, 2010).[9] In Quebec, by 2065, coastal erosion could expose or damage over 5,000 buildings and 294 km of roads, with a combined value of over $1.5 billion (Bernatchez *et al.*, 2015).

2.3.3 Risks to Northern Communities

About 50% of Canada's land mass is underlain by permafrost (NRCan, 1995), and climate change is occurring more rapidly at higher latitudes than in the rest of the country. Northern Canada is experiencing warming temperatures, typified by increases of 2.9°C in the Yukon and British Columbia mountains and 2.3°C in the Northwest Territories between 1948 and 2014 (ECCC, 2015). Between 1968 and 2008, summer sea-ice extent decreased by approximately 2.9% per decade in the Canadian Arctic Archipelago and 10.4% per decade in Hudson Bay (Tivy *et al.*, 2011). Climate risks to, and related impacts on, northern communities[10] and their infrastructure are often highly dependent on their specific location and environment (Furgal & Prowse, 2008; Ford *et al.*, 2016a).

Climate change risks to northerners' health are exacerbating already-existing socio-economic challenges such as lack of housing and poverty. There are increased risks to food and water security and the potential for new food and waterborne illnesses (Ford *et al.*, 2018). For example, increases in rainfall and snowmelt have been followed two to four weeks later with increased visits to health clinics for diarrhea and vomiting in some communities (Harper *et al.*, 2011). Food security may be further compromised by disruptions to hunting or fishing and an increased dependence on store-bought food, which is expensive and often less nutritious (Berry *et al.*, 2014; CCA, 2014). The Special Rapporteur of the United Nations Commission on Human Rights stated that "the effects of global warming and environmental pollution are particularly pertinent to the life chances of Aboriginal people in Canada's North, a human rights issue that requires urgent attention at the national and international levels" (OHCHR, 2005).

Northern residents already report that "environmental changes are impacting their livelihoods, their relationship with the land, their culture, and their mental health and well-being" (Berry *et al.*, 2014). Warming winter temperatures and changing weather patterns threaten northern communities and facilities that rely on sea ice and ice roads (AMAP, 2004; Furgal & Prowse, 2008; Stephenson *et al.*, 2011; Bell & Brown, 2018). Using semi-permanent trails in Nunavut is becoming more dangerous and less dependable due to changes in snow, ice and precipitation patterns, making it more difficult to predict weather conditions, conduct harvesting activities, or travel. Such changes are necessitating the development of new tools for monitoring ice conditions and travel planning (e.g., SmartICE, 2019) (Figure 2.6). In the Northwest Territories, some First Nations are experiencing risks to cultural activities on the land (including building cabins and campfires, trapping, and travelling) as the permafrost thaws (Calmels *et al.*, 2015). Based on Indigenous knowledge and science, Ford *et al.* (2019) found, however, that warming of more than 2 °C over the past 30 years did not lead to an overall reduction in trail access in Inuit regions. Access to sea-ice trails declined while access to land and water trails increased. The critical factors for trail access appeared to be users' level of knowledge and risk tolerance, along with their equipment, rather than climate change.

8. In some coastal regions in Canada, rising sea levels are being offset by ongoing crustal elevation stemming from the melting of the massive ice sheets that covered much of North America in the last ice age. In other areas, including parts of Atlantic Canada, risks from sea-level rise are amplified by ongoing land subsidence.

9. The population figure quoted in the original reference ("220,000") has been updated based on 2016 census profiles of Delta and Richmond, accessible at: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E.

10. The Panel considers northern communities to be those located in the territories and the northern parts of the provinces. Many northern communities are Indigenous communities. Features that distinguish Northern communities from others in Canada may include remoteness, low population density, the presence of permafrost, and more rapid pace of warming compared to southern parts of Canada.

Courtesy of Michael Schmidt

Figure 2.6

Changing Sea-Ice Conditions and Risks to Safety

A SmartICE operator measures sea-ice thickness in Eclipse Sound, Nunavut in March 2018. Changing sea-ice conditions, including more frequent or earlier thaws and thinner multi-year ice, can jeopardize safety for people in northern communities and limit opportunities for practising traditional activities such as hunting and fishing.

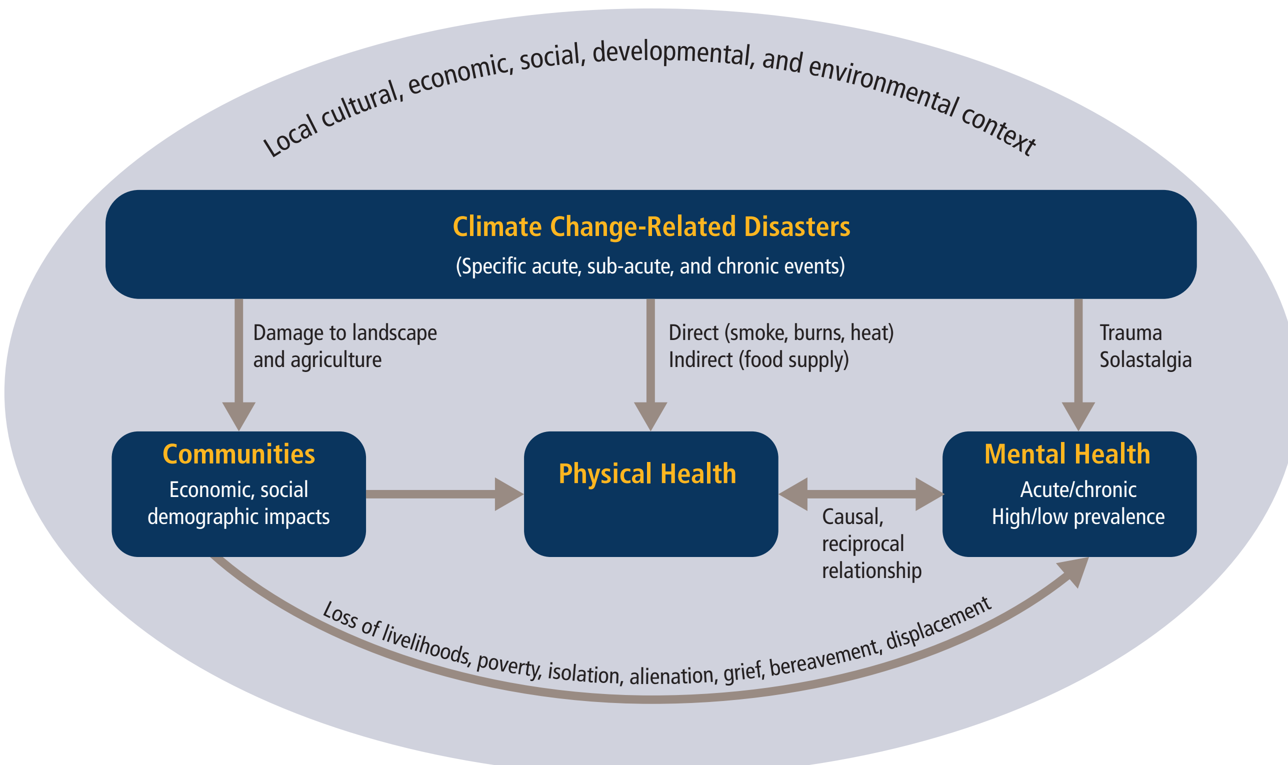
Climate change is also threatening the integrity of community infrastructure, which includes foundations, roads, water and wastewater facilities, and pipelines (NRT, 2010), as well as traditional travel routes. The shortened 2006 ice-road season was estimated to have cost the Diavik Diamond Mine (Northwest Territories) an additional $11 million in fuel transportation costs as it switched from road to air transportation (Pearce, 2011). Changing permafrost conditions can also damage or compromise dams, waste covers, and other mining structures, leading to releases of environmental contaminants (Pearce, 2011; Stratos, 2011).

As temperatures rise and summer seasonal conditions extend, ship traffic for tourism and resource extraction in the Arctic is increasing (Dawson *et al.*, 2018a). While economic opportunities may be created by decreasing Arctic sea-ice extent and increased tourism and resource development, without careful planning they can cause social and economic disruptions in communities unprepared for an increase in visitors (Dawson *et al.*, 2016; Johnston *et al.*, 2017). Transits of the Northwest Passage have increased by 70% since 2006, and the risk of marine accidents is increasing due to more hazardous seasonal ice conditions, with potential consequences for health and safety, northern community integrity and cultural practices, and the environment (Ford *et al.*, 2016a). There are limitations in the quality of Arctic navigational charts, a lack of services, including ports and refuelling opportunities, and limited search and rescue capacity in the region (Ford *et al.*, 2016a). The environmental consequences of marine accidents, including oil spills, in northern waters include direct contact with and contamination of wildlife, contamination of habitats, and long-term transport of oil under sea ice (USNRC, 2014). Few communities have basic oil-spill response kits, and mobilization for response to such disasters in the North requires more time than in more southern locations (USNRC, 2014; CCA, 2016).

2.3.4 Risks to Human Health and Wellness

Risks to human health and wellness from climate change stem from multiple climate drivers. These include: injuries and loss of life from extreme weather events; adverse impacts from lower ambient air quality due to wildfires; increased incidence of infectious diseases spread through water systems; increased ranges of some vector-borne pathogens (e.g., Lyme disease, West Nile virus); adverse impacts on food security; extension of seasonal allergy periods; and short- and long-term impacts on mental health and well-being (Health Canada, 2008; MacDonald, 2008; Berry *et al.*, 2014; Paz, 2015; USGCRP, 2016). The consequences of some of these impacts for public health can be severe. For example, a 2010 heatwave in Quebec increased the death rate across the eight affected health regions by 33%, leading to an additional 279 deaths over a four to five day period (Bustinza *et al.*, 2013).

Berry *et al.* (2018) find that "climate change catalyses a series of reactions which separately and interactively exacerbate risks to mental health and well-being." Figure 2.7 illustrates the causal pathways by which climate disasters affect community well-being, physical health, and mental health. Climate change is widely expected to amplify mental health risk factors and thereby contribute to existing mental health disorders (Berry *et al.*, 2018). The existing gap in access to mental health treatment (MHCC, 2012; Brien *et al.*, 2015; WHO, 2018b) amplifies these risks, which continue to receive little attention in the literature relative to impacts on physical health (Berry *et al.*, 2018). Climate-related disasters can cause trauma and psychological stress, especially for those suffering from human or economic losses. These in turn contribute to a range of cognitive and emotional issues, including post-traumatic stress disorder and depression. Heat, extreme weather events, and worry



Adapted with permission from Berry *et al.* (2010)

Figure 2.7

Causal Pathways Linking Climate Change and Mental Health

Climate change-related disasters often affect communities, physical health, and mental health via multiple channels. There are subsequent interactions among adverse impacts on communities, physical health, and mental health that can exacerbate these impacts. *Solastalgia* refers to "distress that is produced by environmental change impacting on people while they are directly connected to their home environment" (Albrecht *et al.*, 2007).

and loss associated with climate change, can all contribute to the challenge (Berry *et al.*, 2018). Damage to physical infrastructure (e.g., buildings, roads, power grids) can also lead to lack of access to medical care, pharmacies, and social services, putting people further at risk (Berry *et al.*, 2014).

Wildfires can lead to injury and loss of life and can also affect air quality over large areas (thereby exacerbating cardiovascular and respiratory diseases and mortality) (BCCDC, 2018); this can cause widespread disruptions of social and economic activity due to area closures and evacuations, as experienced in the 2015, 2017, and 2018 fire seasons in western Canada (O'Leary & Associates Ltd., 2018; Peak Solutions Consulting, 2018) (Figure 2.8). Air quality can also be adversely affected by climate change due to warmer temperatures increasing concentrations of ground-level ozone (Berry *et al.*, 2014). People in Canada are also experiencing protracted allergy seasons due to climate change. A longer growing season for ragweed (Berry *et al.*, 2014) has led to a significant increase in its spatial distribution and prevalence, an impact already evident in Canada and several parts of the world (EPA, 2008; Lake *et al.*, 2017; Sierra-Heredia *et al.*, 2018) and now affecting about 12% of Quebec residents (Demers, 2013).

Health risks arising from some pathogens are also increasing. The annual incidence of Lyme disease, for example, has increased from 144 cases in 2009 to 2,025 cases as of 2017 (GC, 2018d); the range of the disease appears to be spreading in Canada at a rate of 35 to 55 km per year along climate-determined geographic trajectories (Leighton, 2012).

There can be gendered dimensions and developmental implications to the impacts of climate change on human health and wellness. Research found long-term impacts on immune function in children attributable to the stress experienced by pregnant mothers near Montréal during

Richard McGuire Photo

Figure 2.8

Increasing Frequency and Severity of Wildfires

A bomber plane drops fire retardant on wildfire near Osoyoos, British Columbia in 2013. Wildfire risks are expected to increase in a changing climate (Bush & Lemmen, 2019).

the 1998 ice storm (Cao-Lei *et al.*, 2015). Research finds that natural disasters around the globe reduce life expectancy for women more so than for men; this gap is more pronounced when disasters are more severe and for women with lower socio-economic status (Neumayer & Plumper, 2007). Impacts of climate change on human health and wellness can also undermine human rights, including rights to life, food, water, sanitation, and health (OHCHR, n.d.).

2.3.5 Risks to Ecosystems

Climate is a key driver of the composition, structure, and function of both terrestrial and marine ecosystems, and a changing climate is likely to affect species distribution and result in a loss of biodiversity in most ecosystems (Nantel *et al.*, 2014). Globally, one in six species is threatened due to climate change in a business-as-usual emissions scenario and 8% are expected to become extinct (Urban, 2015). In Canada, the pace of change may exceed the adaptive capacity and resilience of many species and ecosystems (Nantel *et al.*, 2014). Alpine and Arctic ecosystems are thought to be particularly at risk from climate change due to higher levels of expected warming, and limited opportunities for ecosystems and species to shift their ranges (Alsos *et al.*, 2012; Alatalo *et al.*, 2016). As an ecosystem becomes less habitable for a particular species, there can be cascading effects on the distribution of other species due to interdependencies such as predator-prey relationships, and a subsequent loss of biodiversity. Shifts in ecosystem boundaries and species distribution have been documented and will continue to occur as species seek to stay within the climate conditions to which they are adapted (Romero-Lankao *et al.*, 2014). Environmental degradation and loss of ecosystem services could create ecological tipping points that are either irreversible or have no known path to recovery (Dakos *et al.*, 2019). Ecosystem changes can also exacerbate climate change to the extent that they lead to the release of carbon stocks currently held in forests and soils (e.g., a large-scale dieback of the boreal forest) (Lenton, 2011).

Ecosystems and ecosystem services play critical roles in the structure and function of all life on Earth. Impacts on these systems will multiply across social, ecological, and economic dimensions. Human health and wellness are linked to ecosystem health, with natural systems providing food, pollination, water filtration, local climate regulation, erosion control, mental health benefits, and other services essential to human health and wellness (Lindgren & Elmqvist, 2017). Ecosystem changes can degrade the environment's ability to provide ecosystem services to individuals and communities, and change or limit access to traditional, cultural, and spiritual practices (Settele *et al.*, 2014).

Many climate change impacts on ecosystems and species, including northward and upward shifts in plant, mammal, bird, reptile, and insect species, have already been documented in parts of North America (Romero-Lankao *et al.*, 2014). Observed climate changes are affecting the timing of seasonal biological and ecological cycles. For example, the date that Trembling Aspen blossom in Alberta advanced 26 days over the course of the 20th century (Beaubien & Freeland, 2000). In the Arctic, changes in the timing of ice pack formation and break-up are adversely affecting some polar bear populations by reducing their time to feed on seals, thus impairing their health and leading to lower reproductive success (Peacock *et al.*, 2011; Stirling & Derocher, 2012).

In the case of marine ecosystems, increasing carbon dioxide levels in the oceans are changing surface water chemistry, resulting in more acidic environments (Bush & Lemmen, 2019). For marine species such as plankton, pteropods, molluscs, and cold-water corals, ocean acidification impairs their ability to develop calcium carbonate shells or calcified skeletal structures (NOAA, 2019). By one estimate, by 2100, "70% of known cold-water stony coral ecosystems will… no longer be able to maintain calcified skeletal structures" (Herr & Galland, 2009). As a result, these corals will no longer be able to provide ecosystem services such as protecting coasts from erosion and storm surges and regulating water quality. Changes in marine ecosystems and species distribution will also affect fisheries (discussed below) and negatively affect the marine food chain and food sources for coastal communities.

An analysis of impacts on the Lake Saint Pierre freshwater floodplain situated alongside the St. Lawrence River found that climate change-induced reductions in water levels are expected to affect wetlands and shoreline vegetation, water quality, species, recreation, and tourism (Larrivée *et al.*, 2016). The economic value of the impacts of reduced water levels associated with climate change are estimated at between $0.9 and $2.3 billion (Larrivée *et al.*, 2016). Ecosystem impacts can affect industries sensitive to ecological conditions. Warmer winters in western Canada and the United States increase winter survival rates of bark beetle larvae, for example, leading to large-scale forest infestations and forest die-off in recent decades (Bentz *et al.*, 2010). These affect forest industries and their economically dependent communities (Lemmen *et al.*, 2014). For example, about 50% of commercial lodgepole pine in British Columbia has been killed by the mountain pine beetle since the early 1990s (NRCan, 2019b).

2.3.6 Risks to Fisheries

Climate change stands to affect freshwater and marine fisheries in many ways due to warmer water temperatures, lower water quality and levels, ocean acidification, flooding, and extreme weather, as well as indirectly through the expansion of pests and invasive species, among other factors (Campbell *et al.*, 2014; Porter *et al.*, 2014; Pörtner *et al.*, 2014; Settele *et al.*, 2014). Campbell *et al.* (2014) anticipate significant impacts on fisheries via changes in species that support them, in ranges and populations of species, and in increased competition from invasive species. Other studies have noted that Canadian coastal waters feature several "marine hot spots" that are increasing in temperature much more quickly than the global average (Madore & Nguyen, 2017). Changes in marine biodiversity and species distribution stand to affect northern and coastal communities in particular ways, where marine ecosystems are often critical for the local economy and as culturally important food sources (Lemmen *et al.*, 2016).

Some of these impacts are already being observed. In freshwater ecosystems, increases in the temperature of the Great Lakes and its watersheds are expected to favour warm-water fish over cold-water fish such as lake trout (Poesch *et al.*, 2016). In recent decades, increasing water temperatures have resulted in a 60% change in relative recruitment, favouring warm-water over of cold-water fish populations in the Mississippi watershed, and some water bodies have already changed from cool-water fish communities dominated by walleye to warm-water fish communities dominated by species such as pumpkinseed, bluegill, and rock bass (NRT, 2010; Casselman *et al.*, 2011). Cold-water fish habitat in Southern Ontario is projected to decline 67% by 2025 (Chu *et al.*, 2008). Salmon are also likely to be affected by warmer temperatures. Historical warm periods are associated with low salmon abundance in Alaska (Crozier *et al.*, 2008; Karl, 2009), and Pacific salmon stocks from the Fraser River Basin in British Columbia are expected to experience declines. This has implications for fisheries and for Indigenous cultural and spiritual practices revolving around the presence of salmon. Salmon and several other commercial fish species are also expected to decline in Atlantic Canada due to a loss of habitat caused by warmer temperatures (NRT, 2010). Arctic char populations will also likely be affected by increasing temperatures. Estimates suggest that a 1 to 2°C global temperature increase could lead to a 40% or more decline in the range of Arctic char (NRT, 2010). Cold-water fish species across higher latitudes are in general expected to "experience local extinctions and extirpations at large scale" due to higher air and water temperatures (Hasnain *et al.*, 2016).

2.4 OTHER AREAS OF CONCERN

All identified major climate change risks would benefit from dedicated risk-management actions to reduce the possibility of significant damages, disruptions, and losses.

While the six areas of risks discussed in Section 2.3 currently pose the most significant risks to Canada in the Panel's view, climate change poses many other threats (Table 2.2). Many of these risks are interconnected with the top six areas discussed above and have therefore already been introduced. Table 2.2 draws out some additional impacts relating to the other six risk areas.

Agriculture and Food

While agricultural food production is anticipated to modestly increase in the medium term, increased exposure to drought conditions as well as rising average temperatures will nonetheless pose some risks for agricultural production across Canada (Campbell *et al.*, 2014). Climate variability will challenge the business model of farms by increasing the uncertainty associated with the range of future conditions a farmer can expect. Impacts of climate change on international markets are another source of uncertainty, with reductions in agricultural production in many developing countries likely to increase demand for Canadian agricultural exports (Campbell *et al.*, 2014). Fletcher and Knuttila (2016) found that vulnerability to drought has a gendered component among farming households in Saskatchewan. In particular, "gender roles and ideologies made men more vulnerable to the psychological consequences of drought, challenging conventional discourses that feminize vulnerability." In addition, environmental crises can further entrench historical gender roles by creating additional caregiving, farm, and off-farm work for women (Fletcher & Knuttila, 2016).

Forestry

Impacts to forests and thus the forest industry from climate change include direct effects such as changing weather patterns affecting tree growth and production, and indirect impacts, such as changes in wildfires, and shifting ranges of invasive species and pests causing changes in the forest structure (NRT, 2010). The specific impacts to forests due to climate change in Canada are dependent on regional conditions and are not considered to be uniform across the country (NRT, 2010). The rate at which forests are anticipated to change is estimated to be beyond the natural capacity for forest species to sufficiently adapt (Lemmen *et al.*, 2014). Pest outbreaks (e.g., mountain pine beetle), increases in the number and severity of forest fires, and increases in tree mortality have all been linked with climate change (Sambaraju *et al.*, 2012; Lemmen *et al.*, 2014; Romero-Lankao *et al.*, 2014).

Geopolitical Dynamics

Climate change could have wide-ranging geopolitical implications (Barnett, 2007; Barnett & Adger, 2007; Dyer, 2009; Dalby, 2013; Adger *et al.*, 2014), impacting federal policy and actions in many areas, and contributing to increasing international, economic, humanitarian, and geopolitical risks in ways that are difficult to anticipate. Humanitarian crises abroad could intensify demand for humanitarian and foreign assistance, and potentially lead to political destabilization and an increased likelihood of conflict in some regions (Adger *et al.*, 2014). Climate change could also create additional strains on relationships with Canada's major trading partners and allies, including the United States. Extensive infrastructure and trade link Canada and the United States; many geographic and ecological systems span their shared border, including watersheds, ecosystems, and species range. Canada and the United States (and other northern countries) share borders in the Arctic and have joint interests in managing Arctic resources and transportation routes. Freshwater resources could also become a source of geopolitical tension (Lonergan & Kavanagh, 1991; Petersen-Perlman *et al.*, 2017) as some regions and countries face increasing levels of drought and shifts in water availability due to reduced snow and ice cover. By creating new challenges and opportunities, climate change has the potential to destabilize international relationships and exacerbate existing tensions (Ebinger & Zambetakis, 2009).

Table 2.2
Other Climate-Related Risks Facing Canada

Area of Risk	Potential Hazards or Impacts
Agriculture and Food	• Drought • Heatwaves • Heavy precipitation events/storm damage • Pests/invasive species • Disruption of global food system or global food supply chains
Forestry	• Drought/changing precipitation patterns • Wildfire • Pests/invasive species
Geopolitical Dynamics	• Increasing international migration • Increasing need for humanitarian assistance for climate-related disasters • Increasing geopolitical conflict over climate-affected resources • Increasing geopolitical conflict and tension over Arctic territory and resources
Governance and Capacity	• Failure to achieve international cooperation/agreement on policies for reducing emissions and managing risks • Failure to develop the capacity to proactively adapt and plan for climate risks on timeframes of decades or longer • Loss of confidence in government related to the above failures
Indigenous Ways of Life	• Reduced opportunities for cultural activities such as hunting, fishing, and foraging • Damage to cultural sites due to permafrost thaw, sea-level rise, and coastal erosion • Effects on the integrity of Indigenous cultures and economies • Adverse effects on social and cultural cohesion and intergenerational knowledge transfer
Water	• Reduced water supply due to changing precipitation patterns and runoff timing/conditions • Diminished water quality (and increased cost of water treatment) due to heavy precipitation events, and algae and other microorganism growth • Damage to water systems (e.g., treatment facilities, pipelines, reservoirs, dams) from extreme weather events • Increased potential for conflict over water resources

Listed impacts were identified by the Panel based on members' own knowledge and evidence from sources including NRT (2010); Downing and Cuerrier (2011); Romero-Lankao *et al.* (2014); Warren and Lemmen (2014b); King *et al.* (2015), and Ford *et al.* (2018).

Governance and Capacity

In the Panel's view, risks related to failures in governance could have widespread implications. The complex interconnections among climate risks and infrastructure, health, and essential services, combined with the high cost of repairing damage or proactively adapting, may leave governments — especially smaller local governments, which are on the front lines when climate-driven disasters occur — unable to respond. Government failures to adequately prepare for climate change could jeopardize essential public services and damage the public's trust in government, further hindering government efforts to engage with the public on the need to prepare for climate change impacts and manage climate-related risks. Such failures could also exacerbate regional tensions in Canada, and make effective domestic and international intergovernmental cooperation on climate action more difficult.

Indigenous Ways of Life

Risks to Indigenous ways of life are often interconnected with risks to species, ecosystems, and coastal and northern communities. Climate change is leading to a loss of opportunities to practise cultural activities such as harvesting (Downing & Cuerrier, 2011), resulting in additional financial strain on households (ITK, 2016). There is an increase in the risk of physical harm associated with some traditional activities (e.g., hunting on sea ice) (Watt-Cloutier, 2015). Inuit report that climate-driven changes to the environment (e.g., ice, snow, wildlife) are negatively affecting mental health and well-being (Willox *et al.*, 2013). Ecosystem conditions underpinning Indigenous ways of life are changing with such rapidity that Indigenous Peoples are finding it more difficult to predict natural processes than before (Downing & Cuerrier, 2011). Some Elders report that, within one generation, climate change has increased the unpredictability of the environment and decreased the reliability of Indigenous knowledge. While Indigenous Peoples are accustomed to adapting to changing environments, the more rapid fluctuations encountered now are leading to a disconnection with the land (Downing & Cuerrier, 2011). As a result, climate change is affecting the integrity of Indigenous cultures and economies (Whyte, 2017) and may also adversely affect social and cultural cohesion and intergenerational knowledge transfer (Ford *et al.*, 2006).

Water

Water supply and quality could also be compromised. Climate change is expected to cause variations in seasonal precipitation patterns, increase glacial melt, and cause earlier spring runoff (Bush, 2014). The costs of drought can be significant. The 2001–2002 drought that extended across much of Canada reduced GDP by approximately $6 billion (Wheaton *et al.*, 2008). Remote communities and Indigenous Peoples are particularly vulnerable to reductions or changes in reliability of water supplies (Andrey *et al.*, 2014). Areas where competition for water resources already exists, such as the southern interior of British Columbia, southern Prairies, and southern Ontario, are also more vulnerable (Andrey *et al.*, 2014). Risks to water supplies, particularly from drought and glacier loss, exacerbate many of the top risks identified by the Panel, influencing health, infrastructure, and communities.

The magnitude and complexity of all 12 areas of risk call for concerted efforts by governments, businesses, and society at large to assess and pursue adaptive responses that reduce risk, and to prepare to cope with residual risks. This is the subject of the next chapter.

3

Assessing Adaptation Potential

KEY FINDINGS

- All 12 areas of climate change risk considered by the Panel can be meaningfully reduced through adaptation measures that lessen vulnerability or exposure. However, no risk can be completely eliminated through adaptation, so decision-makers need to anticipate and plan for consequences that are unavoidable.
- Adaptation potential varies across the major areas of climate change risk. Risks to human systems often permit a range of adaptation actions that can prevent or reduce future harm. Risks to natural systems can be more difficult to address, particularly when the pace of climate change exceeds their innate capacity to adapt. Protecting and enhancing ecosystem resilience by accelerating conservation efforts, reducing anthropogenic stressors, and restoring ecosystems are key adaptive strategies in these cases.
- Adaptation is complicated by interconnections among the responses to different areas of risk. These interconnections can create opportunities to address multiple risks with a single set of solutions. However, policies may also have the potential to reduce risk in one area while increasing risk in another. Avoiding maladaptive solutions requires a deep evidence-based understanding and analysis of potential interactions, as well as coordination and cooperation.

Adaptation measures reduce vulnerability and exposure, thereby reducing the degree of risk posed by climate change. This chapter reviews the adaptation potential associated with the 12 areas of climate risk considered by the Panel. The joint consideration of risk level and adaptation potential presents a potentially powerful tool for government to use when prioritizing its actions with respect to all risk areas.

3.1 UNDERSTANDING ADAPTATION POTENTIAL

Climate risks arise from the interactions of climate-related hazards, vulnerabilities, and exposure (Section 2.1). Actions to reduce climate risks can therefore be divided into three corresponding groups: (i) actions that reduce climate-related hazards; (ii) actions that reduce vulnerabilities; and (iii) actions that reduce exposure. Climate-related hazards are driven by the climate system, and emissions mitigation is the primary means for moderating or reducing such hazards over the long term.[11] Adaptation actions reduce risk by decreasing vulnerability or exposure, and some measures can address all three dimensions (e.g., urban tree planting can moderate the urban heat-island effect, lower air-conditioning demand, reduce atmospheric carbon, and improve air quality and therefore health (Nowak & Heisler, 2010)). The Panel adopted the IPCC's definition of *adaptation*, which is "the process of adjustment to actual or expected climate change and its effects;" in human systems, this is undertaken to "moderate or avoid harm or exploit beneficial opportunities" (IPCC, 2014a).[12] There are a number of ways to categorize adaptation measures. Often consideration is given to hard technologies (e.g., coastal defences), ecosystem-based adaptation, and soft measures related to building adaptive capacity (e.g., legislation or insurance) (UNFCCC, 2006).

11. The role of mitigation in reducing risk was beyond the scope of this assessment. Sustainable land and water use planning can also contribute to hazard reduction. Geoengineering options such as solar radiation management could also reduce climate-related hazards on a global scale, though these options also entail significant risks.
12. Note that an assessment of opportunities associated with climate change was determined by the Panel to be beyond the scope of this assessment (Section 1.2.3).

3.1.1 Adaptation to Manage and Reduce Exposure

Exposure to climate change impacts is associated with physical locations that put populations and/or systems in harm's way (Oppenheimer *et al.*, 2014). Houses located in a floodplain, for instance, face greater risk due to their heightened exposure. Facilities and infrastructure in coastal areas are often exposed to high-tide flooding, storm surges, and high winds from coastal storms (Lemmen *et al.*, 2016). As a long-term adaptation response to climate change, people, communities, and industries may need to reduce or eliminate risk by physically relocating to less-exposed areas. Exposure can also be moderated through adaptations that reduce the potential for damages or negative impacts. Sea walls, dikes, and modified land use in coastal areas can reduce exposure to sea-level rise and coastal flooding without requiring relocation of physical infrastructure; exposure could increase, however, if development increases behind such measures when there continues to be a risk of overtopping.

3.1.2 Adaptation to Reduce Vulnerability

Vulnerability includes biophysical and socio-economic dimensions (Nelitz *et al.*, 2013). Some sources of vulnerability exacerbate many or all climate-related risks while others are risk-specific. As discussed in Section 2.1, some populations are more vulnerable to climate risks due to their reduced adaptive capacity[13] and resilience in the face of external stressors. Interventions that act on the drivers of vulnerability could therefore be targeted to enhance adaptive capacity. These include interventions that address poverty, unemployment, and lack of access to healthcare, education, and housing. Along similar lines, the Government of Canada's Expert Panel on Climate Change Adaptation and Resilience Results identified reconciliation as "an enabling condition for the resilience of Indigenous Peoples to climate change" (EPCCARR, 2018). Public policy interventions oriented to these outcomes can reduce the severity of climate change risks by enhancing the resilience of vulnerable populations.

Physical vulnerability is more context- and risk-specific. For example, species adapted to Arctic or high-alpine ecosystems do not have the ability to migrate in the same way as those at lower latitudes and/or altitudes, making northern species vulnerable to climate change in a distinctive way (Furgal & Prowse, 2008; Nantel *et al.*, 2014). Natural resource industries often have unique vulnerabilities due to their high degree of climate sensitivity and the potential for disruptions to ecosystems they depend on (Lemmen *et al.*, 2008, 2014). Strategic shifts in resource industry approaches to forestry and fisheries management can contribute to ecosystem integrity and improve ecosystem resilience to climate change. Urban environments can be more or less vulnerable to inland and coastal flooding depending, in part, on the capacity of storm drains and their state of maintenance, diversion systems and dikes, and the presence and use of natural ecosystem services such as wetlands (Ramsar Convention, 2018).

3.1.3 Variability in Adaptation Potential and Feasibility Across Risks

Adaptation options can vary widely in their scale and potential costs, and sometimes options are few and of limited effectiveness in avoiding or offsetting adverse impacts (e.g., responses to sea-level rise in urban areas). However, the costs of adaptation are often significantly lower than the costs of inaction (NRT, 2011). The feasibility of adaptation interventions often depends on scale (e.g., the size of the affected geographic area, number of people), the cost of intervention, the time required, the capacity and willingness to undertake the actions, and the extent of collaboration or cooperation needed among adaptation actors at all levels. Conflicts over who should incur adaptation costs can result in failure. However, understanding of both the barriers to adaptation and how those barriers can be overcome is improving in Canada (Eyzaguirre & Warren, 2014).

3.2 ASSESSING ADAPTATION POTENTIAL BY RISK AREA

The Panel's approach to considering adaptation potential was consistent with that taken in other adaptation assessments, whereby "[a]daptations are considered to assess the degree to which they can moderate or reduce negative impacts of climate change" (Smit & Wandel, 2006). Adaptation potential was assessed through a process similar to that used for risk assessment. During the workshop, participants were asked to assess and discuss the extent to which adaptation actions (beyond those already underway or planned) could reduce or eliminate the adverse effects associated with climate risks. Initial assessments were then revised based on collective discussion and deliberation. Building on workshop results, the Panel undertook a final assessment that focused on the 12 main areas of risk identified in Chapter 2, reflecting on the proportion of damages that could be avoided through an appropriate combination of adaptation actions (see Appendix for additional details). Figure 3.1 shows the results of this assessment.

13. Agard *et al.* (2014) define *adaptive capacity* as "[t]he ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences."

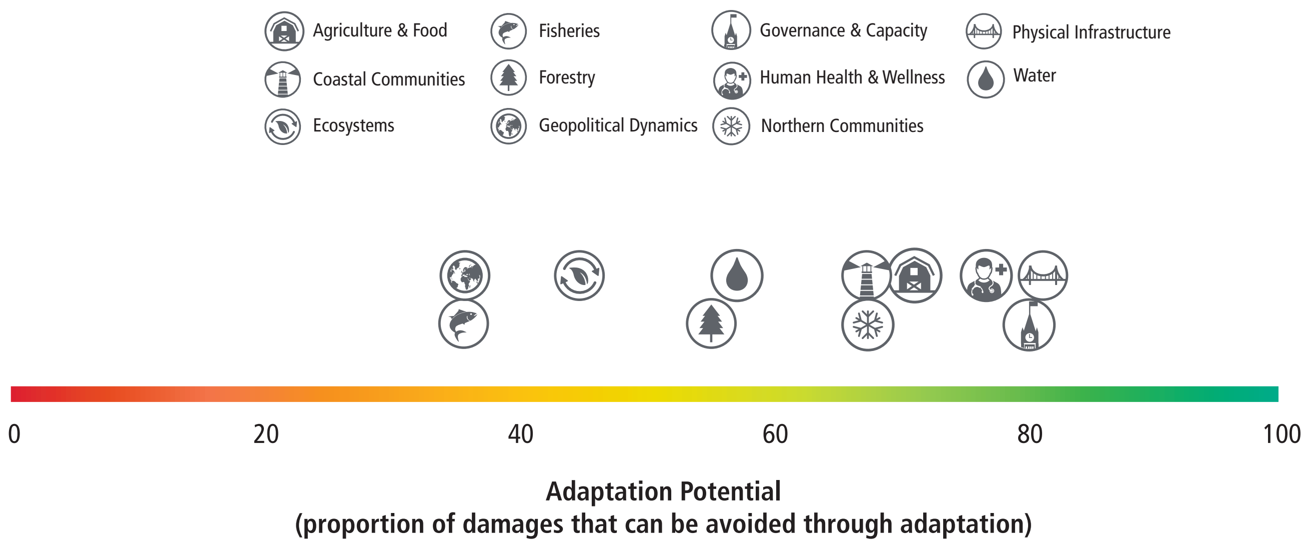


Figure 3.1

Panel Assessment of Adaptation Potential by Risk Area

This graph illustrates the ascribed results of the adaptation potential assessment by risk area. The Panel could not produce a defensible evaluation of the adaptation potential of Indigenous ways of life due to the lack of Indigenous members on the Panel and limited inclusion of Indigenous knowledge in the assessment.

Through the process of conducting the assessment, the Panel concluded that it could not produce a defensible evaluation of the adaptation potential of Indigenous ways of life due to the lack of Indigenous members on the Panel and the limited inclusion of Indigenous knowledge. For this reason, the Indigenous ways of life risk area is not shown in Figures 3.1 or 3.3. Given the importance of this risk at the national level, however, it is still discussed in the text.

3.2.1 Analysis

The assessment presented in Figure 3.1 has several useful implications for understanding the role and promise of adaptation in responding to climate change risks generally. In all cases, targeted adaptation actions (or a portfolio of actions) can reduce the damages or costs that could arise as a result of climate change. At the higher end of the spectrum, the Panel judged that over 75% of the associated costs, damages, or disruptions from climate risks to physical infrastructure, governance and capacity, and human health and wellness could potentially be avoided over the 20-year timeframe. Similarly, in the opinion of the Panel, risks to northern and coastal communities and risks to the agriculture and food system have a high potential for adaptation over the 20-year timeframe. Additional research could identify new adaptation strategies and enhance the adaptation potential across areas of risk. At the same time, no risk can be completely eliminated through adaptation alone, and decision-makers need to anticipate and plan for residual risks.

In the Panel's view, assessing adaptation potential is to a large extent dependent on the degree of human control over each risk area. Climate risks to natural systems are more difficult to manage than risks to human systems due to the complexity of natural systems, the limited range of available interventions, and the inability of natural systems to adapt quickly enough to a changing climate. Protecting and enhancing ecosystem resilience by accelerating conservation efforts and restoring ecosystems in critical areas are key adaptive strategies for risks involving natural systems (IUCN, 2017). Other anthropogenic impacts and stressors such as habitat loss and fragmentation as well as ecosystem degradation can amplify climate-related risks to natural systems (Nantel *et al.*, 2014; Settele *et al.*, 2014). Reducing or reversing these impacts decreases the overall stress on these systems and can moderate their vulnerability to climate change.

Urban development, intensive agriculture, and overexploitation of water resources can adversely affect ecosystems and individual species. Cumulative risk assessments can be applied to land- and water-use management decisions to ensure they do not aggravate ecosystem damage that can worsen human system vulnerability (Parkes *et al.*, 2016). For instance, urban development and the removal of wetlands for development in Houston, Texas significantly aggravated the 2016 and 2017 flooding (Zhang *et al.*, 2018). Increased land and water conservation activities (at wider scales than currently used) can aid in protecting and preserving the resilience of natural systems and the co-benefits these bestow on human systems, which are increasingly being quantified and formalized (MNAI, 2017). In the greater Montréal area alone, for example, ecosystems and biodiversity have been estimated to provide approximately $2.2 billion dollars annually in non-market goods and services (Dupras *et al.*, 2015).

3.2.2 Adaptation Options by Risk Area

Indigenous Ways of Life

Given the lack of Indigenous members on the Panel, and only limited inclusion of Indigenous knowledge in the assessment, the Panel realized it could not present a defensible rating of the adaptation potential. The Panel recognizes that Indigenous ways of life are eminently adaptable and the potential to reduce these risks is aided by Indigenous individuals' and communities' capacity to adapt to a changing environment. While non-Indigenous societies often frame the problem of climate change in catastrophic terms (Methmann & Rothe, 2012), Indigenous Peoples have demonstrated a capacity for adaptation, resilience, and survival in the face of the pervasive social, cultural, and environmental changes over the course of colonial history, and during major ecological changes in the thousands of years living on the land (Kimmerer, 2014; Whyte, 2018). Some Indigenous people view climate change as yet another situation requiring adaptation (Whyte, 2018), however, the multiplicative effects of climate change, when combined with the effects of colonialism, power differentials in Canadian society, marginalization, land rights, and loss of land may affect adaptation success (Ford *et al.*, 2016b).

The nature and degree of climate-related impacts on Indigenous ways of life will vary by region, as will the cultural considerations involved in responding to them. While many Indigenous people are managing to cope with current climate change impacts, a time may come when this is no longer possible; proactive adaptation measures are therefore very important as means of anticipating and planning for future stresses (CIER, 2008). The Panel did not consider it its place to assess adaptation potential at the community level, given its mandate to conduct a national-level assessment. Indigenous communities themselves are best positioned to understand and respond to specific, local risks, and the federal government's affirmation of self-determination along with the *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP) could support collaborative action on adaptation. National Indigenous organizations, various Indigenous governments in Canada (e.g., AFN, 2017b; ITK, 2017), and the Truth and Reconciliation Commission (TRC) have called upon "federal, provincial, territorial, and municipal governments to fully adopt and implement the United Nations Declaration on the Rights of Indigenous Peoples as the framework for reconciliation" (TRC, 2015). While the federal government has not yet ratified UNDRIP, a private member's bill was tabled in Parliament with the aim of implementing the Declaration (GC, 2019a). As of May 2019 this bill had completed second reading in the Senate.

Managing risks effectively will require respect for and reliance on Indigenous knowledge through collaborative approaches that span multiple jurisdictions. According to the CCA's Expert Panel on the State of Knowledge and Practice of Integrated Approaches to Natural Resource Management in Canada:

> More inclusive forms of governance with a broader set of actors and expanded ways of knowing… legitimize and improve the quality of decision-making. In this context, inclusion depends on fair opportunity to participate, procedural fairness, and substantive fairness in outcomes. Effective governance also explicitly incorporates the multilevel legal jurisdiction...
>
> (CCA, 2019)

Environmental and geographic conditions may limit opportunities to practise Indigenous ways of life in a changing climate. However, the opportunities for Indigenous practices to evolve in response to these changes are many and varied.

Physical Infrastructure

With careful planning and investment, much of Canada's physical infrastructure can be made more resilient to climate-related risks. Climate risks to physical infrastructure can be managed through actions such as ensuring that building codes and design standards take climate projections into account, and investing in transportation systems, electricity grids, power and communications systems, and other critical infrastructure to improve their resilience in the face of climate-related damages or shocks (Boyle *et al.*, 2013; Andrey *et al.*, 2014). Because much of Canada's existing infrastructure is aging, climate-related risk assessments and vulnerability analyses must be incorporated into maintenance, upgrading, and lifecycle management programs in order to increase the resilience of Canada's stock of infrastructure in the face of these risks. Recent research suggests that this is rarely happening in practice; a recent review of municipal adaptation plans from across Canada found that few municipalities have assessed their vulnerability (Guyadeen *et al.*, 2019). Long infrastructure lifespan increases the need for planned adaptation actions to prepare for climate risks that will emerge in future decades (Hallegatte, 2009). While the costs of incorporating future climate conditions in infrastructure design may be considerable, they tend to be small relative to the costs of rebuilding or repairing infrastructure in the future (World Bank, 2016).

Governance and Capacity

According to the Panel, governments can protect themselves and people in Canada against climate change risks by taking into account how climate change might affect operations, policies, and programs; by ensuring climate change is incorporated into their risk management practices; and by being transparent with the public about policies used to achieve emissions reduction and support adaptation. In general, governments can minimize this area of risk by developing internal capacities to understand, anticipate, and respond to climate change so they can continue to deliver essential public services, policies, and programs (discussed further in Chapter 4). However, for local governments, adaptive infrastructure upgrades are often beyond existing human and financial capacity, and funding and policy related to building this capacity remain fragmented across Canada's three levels of government. The Federation of Canadian Municipalities and the C40 Compact of Mayors both offer programs to support local adaptation (FCM, 2018; C40 Cities, 2019).

Human Health and Wellness

Health risks related to climate change can be managed through a variety of interventions (Health Canada, 2008; Berry *et al.*, 2014; Smith *et al.*, 2014). Generic interventions to improve a range of health outcomes include the reduction of socio-economic disparities and the enhancement of protection and support for vulnerable populations, for instance by enhancing access to and quality of health and social care facilities, and supported housing (WHO, 2018a, 2018b). Heat-related impacts can be managed through measures including issuing timely public advisories and announcements, providing sufficient access to air conditioning and green spaces, and ensuring power grids are resilient in the face of rising demand for cooling in the summer (Berry *et al.*, 2014). Adverse impacts on mental and physical health can be reduced through comprehensive disaster preparedness and relief and recovery operations combined with long-term, sustained, physical and mental health support programs. Emerging zoonotic threats to health associated with climate change can be partially managed through public advisories, training, and outreach initiatives as well as targeted management of pest/carrier populations (PHAC, 2014). Continued research into these diseases is also needed to develop new treatment strategies. Current treatment options for late-stage (disseminated) cases of Lyme disease are limited, leading to the potential for significant disability and decreased quality of life (Hu, 2016). Monitoring is required for emerging health risks related to the spread of vector-borne diseases for which people in Canada are not yet prepared.

Agriculture and Food

Risks to agriculture and food systems can be managed through a variety of actions (Campbell *et al.*, 2014; Porter *et al.*, 2014). The effects of drought, heatwaves, and changes in precipitation can be managed in some cases by adopting varieties better able to handle these stresses, or by developing equipment and strategies to protect crops from climate-related shocks, including drought and flooding (Porter *et al.*, 2014). In some cases, agricultural producers may be forced to shift to alternative crops better suited to changing weather patterns, establish new growing areas in alternative locations, or use greenhouses (though this option may be prohibitively costly). Agricultural systems, however, are fundamentally reliant on water availability, soil quality, weather patterns, and terrestrial ecosystems, and there are limits to the types and amounts of stress that most agricultural crops can tolerate. Coupled with social, economic, and institutional factors, these constraints can create significant barriers to adaptation in food systems (Porter *et al.*, 2014).

Coastal Communities

Many coastal communities face the risk of high-tide flooding and storm surges and some face long-term irreversible inundation due to sea-level rise (Lemmen *et al.*, 2016). While management of these risks can require long-term planning and large capital investments, dikes, seawalls, and appropriate land-use planning can help protect vulnerable areas, and building codes can be modified to include design criteria for structures in coastal zones exposed to extreme weather events and/or higher sea levels. Improving sea dikes and protective defences for the Metro Vancouver coastal shoreline and the Fraser River shoreline, totalling 250 km, in anticipation of sea-level rise by the end of this century, is estimated at $9.5 million (Delcan, 2012). However, an analysis of the direct and indirect costs of storm surges and sea-level rise through to mid-century found that adaptation investments tended to provide overall economic savings, particularly in more populated areas (Withey *et al.*, 2016). Another analysis found that policies of prohibiting new development in areas facing flooding risk and strategically retreating from these areas (by rebuilding flooded homes in other non-flood prone areas) could both lower costs (NRT, 2011).

Northern Communities

In northern communities, permafrost degradation poses significant risks to buildings and transportation systems. An analysis of the costs of adapting building foundations to thawing permafrost across six Northwest Territories communities suggests costs could be in the hundreds of millions of dollars territory-wide (Hoeve *et al.*, 2006). Protecting structures against changing permafrost conditions can be costly, but options exist (SCC, 2014). Snow removal can help keep the ground cold and prevent melt-water pooling. Ensuring that structures built on permafrost are elevated off the ground to allow cold-air circulation, with suitable foundation types (e.g., space frames, screw jacks, deep pilings) can reduce thawing and enhance a building's resilience. Technologies for passively cooling the ground under and around buildings and roads on permafrost also exist (e.g., thermosiphons) (SCC, 2014). Careful consideration of siting in future developments in the North will be important for managing risks from permafrost degradation and coastal erosion.

Northern communities' ability to adapt to climate change depends on interconnected factors such as housing, poverty, food security, and traditional skills. These factors are key to maintaining cultural identity, and health and well-being. As noted in Section 2.3.3, with the loss of sea ice, Inuit use of trails has changed; sea-ice trail use has declined but travel on open water (by boats) and over land has increased (Ford *et al.*, 2019). Nevertheless, while Inuit are highly adaptable, the rapidity and degree of change in the Arctic is making adaptation more difficult in some situations (Robb, 2015; Watt-Cloutier, 2015; Gov. of NU, n.d.).

Successful climate risk management and adaptation in Inuit communities consider climate risks along with documented social determinants of Inuit health such as: "quality of early childhood development; culture and language; livelihoods; income distribution; housing; personal safety and security; education; food security; availability of health services; mental wellness; and the environment," (ITK, 2016). Figure 3.2 illustrates the connections among climate risks, impacts on humans, and potential adaptation actions for Inuit.

Water

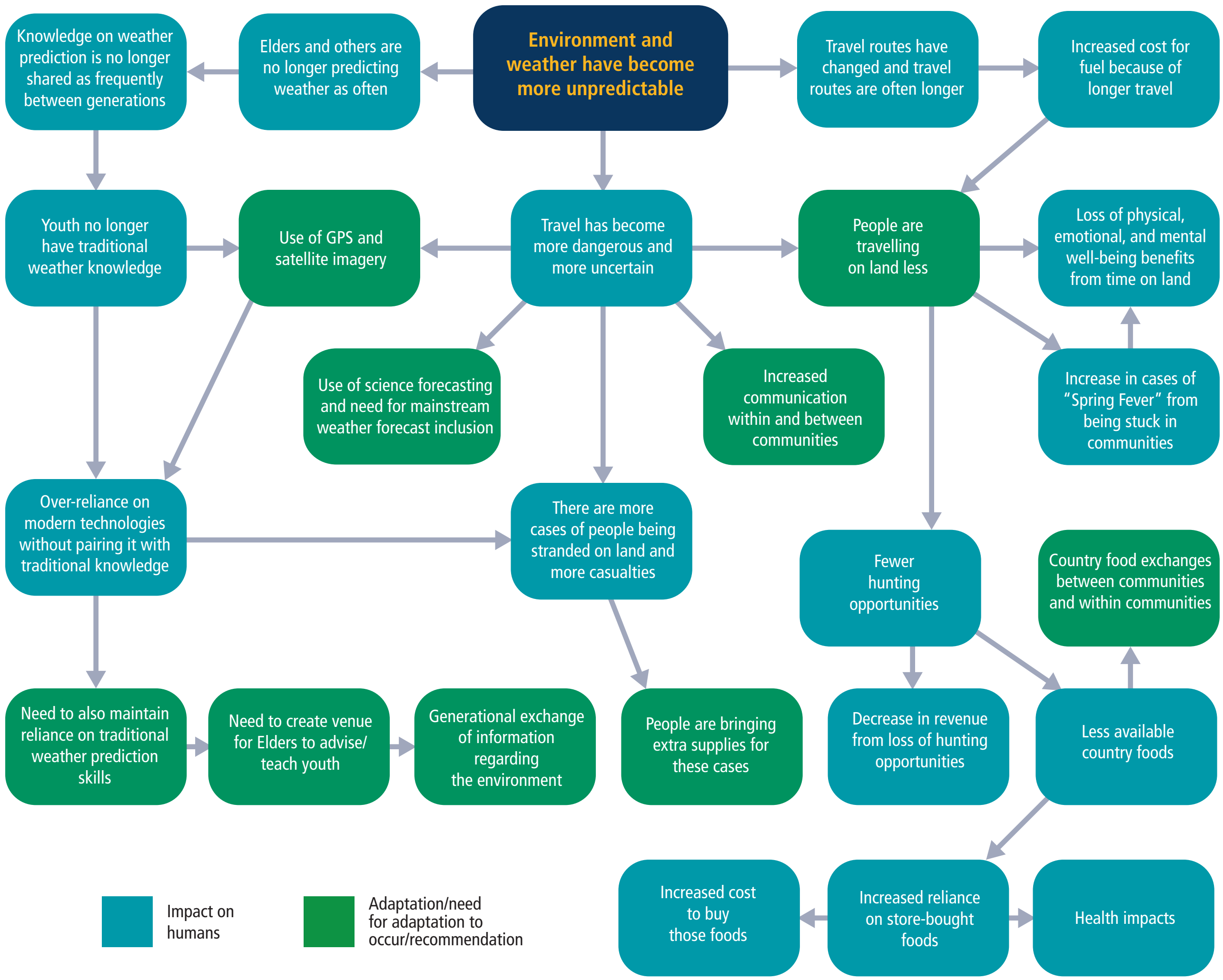
Romero-Lankao *et al.* (2014) note that some adaptive responses to changes in the supply and quality of water are beneficial even in the absence of climate change, such as enhancing green infrastructure and reducing current water waste. New and improved infrastructure can support adaptation to water scarcity in some instances, but many other options, including water conservation measures and new storage measures to offset the loss of snow and ice cover, are also needed (Andrey *et al.*, 2014). Adjusting watershed level planning to account for future climate can also support informed decision-making (NRT, 2010). A robust and reliable water supply is foundational to all aspects of life, so actions to adapt to these risks can therefore provide a range of co-benefits for other climate change risk areas, and multiple benefits for other risks.

Forestry

Canada's forest sector has been an early actor in advancing climate change adaptation, motivated by pest outbreaks such as the mountain pine beetle, and intense wildfire seasons (Lemmen *et al.*, 2014). Strategies that can potentially improve the resilience of forests to emerging climate conditions include: land and ecosystem management practices; pest management programs; breeding programs for disease-, pest-, and drought-resistant tree species; assisted species migration; and supported recovery after episodes of forest disturbance (USDA, 2016). The timeframes associated with forestry activities complicate climate change adaptation: tree-planting decisions made today will carry effects far into the future (Lemmen *et al.*, 2014). Conducting forestry planning activities over shorter time horizons, factoring future climate projections into planning, and applying adaptive management approaches can enable more responsive decision-making (Lemmen *et al.*, 2014; CCA, 2019). Edwards *et al.* (2015) underscore the importance of factoring in local context, highlighting the important role of forest practitioners in integrating government, scientific, and community knowledge and perspectives into forest-planning decisions. Innovation in the forestry sector is also recognized as an important tool for facilitating climate adaptation (e.g., Natural Resources Canada's Forest Innovation Program) (NRCan, 2018b).

Ecosystems

Climate-related threats to ecosystems and species can be managed in some cases through supporting or amplifying the natural capacity of these systems to respond to a changing environment (Settele *et al.*, 2014). For instance, facilitated migration or transplantation can aid species as they seek to move into new habitats, as can urban and other infrastructure planning that allows species movement, such as culverts and corridors. It may also be necessary to begin considering shifts in park boundaries and protection of other



Adapted with permission from Nickels *et al.* (2005)

Figure 3.2

Inuit Observations, Impacts, and Adaptation Diagram

This diagram presents actual and potential adaptation actions for Inuit regions when responding to climate change impacts deriving from more unpredictable weather and environmental conditions.

eco-regions as conditions change. In addition, scientists and researchers may sometimes be able to accelerate evolution and natural selection to aid adaptation. Researchers are exploring two of these strategies (selective breeding and assisted migration) to support climate change adaptation in Canada's forests (Ste-Marie, 2014; MacLachlan *et al.*, 2017). Conservation measures such as expanding protected areas, offering incentives for private land preservation, and deploying economic instruments that place a value on ecosystem services can all enhance resilience by maintaining or improving the overall health of natural ecosystems (SP, 2011; Nantel *et al.*, 2014; GC, 2017b).

Geopolitical Dynamics

Climate change also has significant geopolitical dimensions (Barnett, 2007; Barnett & Adger, 2007; Podesta & Ogden, 2008; Dalby, 2013). In the view of workshop participants and the Panel, climate change impacts occurring outside of Canada will also increasingly create risks related to national security, access to imports and export markets, and humanitarian crises. The ability to manage or reduce these types of risk is constrained by a nation's limited ability to influence affairs occurring outside its territorial jurisdiction. However, actions may still be able to moderate these risks through Canadian leadership on the international stage. The Panel notes that strong action at home would help legitimize leadership efforts internationally. Potential actions include supporting other countries through foreign aid and international partnerships as they work to develop their adaptation capacity and resilience to climate shocks (Adger *et al.*, 2014); targeting foreign aid to address climate vulnerabilities in developing countries and to reduce the risk of humanitarian crises (Klein *et al.*, 2014); and working with international allies and partners to respond to specific risks, such as strengthening cooperation with other Arctic countries (e.g., through the Arctic Council) to address changing conditions in the Arctic, while exercising sovereignty over Canada's North (Griffiths *et al.*, 2011; Lackenbauer & Huebert, 2014). Finally, domestic actions — including federal government planning that considers climate-related trends and the resulting potential for geopolitical crises — may help prepare for international climate-related risks.

Fisheries

In the context of fisheries, much of the potential for adaptation lies in enhancing the resilience of aquatic ecosystems. Fishery closures, reduced catch quotas, and marine protected areas can all help to maintain or improve ecosystem health (Smith & Sissenwine, 2001; Jessen & Patton, 2008). However, the economic, social, and cultural context varies across Canada's fisheries, and the choice of adaptation measures should be informed by the local situation (Worm *et al.*, 2009; Mercer Clarke *et al.*, 2016). Adaptation can be particularly challenging for communities that rely heavily on a single fishery, and can have widespread economic and social consequences (Mercer Clarke *et al.*, 2016). A combination of approaches, including catch quotas, community management, regulations on fishing gear, ocean zoning, and economic incentives, can help manage and restore marine fisheries and ecosystems (Worm *et al.*, 2009).

3.3 CAPITALIZING ON ADAPTATION POTENTIAL

Protecting against climate risks requires adaptation actions tailored to expected, specific adverse impacts and to the unique characteristics of the systems at risk. The Panel underscores the widely accepted imperative for "mainstreaming" adaptation (i.e., incorporating assessments of climate risks into existing decision-making processes and approaches to risk management). The Panel also notes the importance of developing pathways to adaptation now; course corrections and enhancements can be implemented as capacity and knowledge improve. In the Panel's view, taking a holistic perspective can help inform adaptation decision-making by factoring in co-benefits and looking for adaptation strategies that provide solutions to multiple challenges, even beyond the realm of climate change. The Panel and workshop participants pointed to several overarching considerations that help capitalize on adaptation potential, minimize risk, and avoid adaptation pitfalls.

3.3.1 Interacting Effects

Adaptation initiatives implemented across a variety of domains can have interacting effects, which can amplify or interfere with each other.

Adaptation actions that target more than one risk have the potential to interact with each other in ways that may be complementary, synergistic, or conflicting. In many cases, climate risks share common sources of vulnerability (Section 2.1). Strategies that reduce vulnerability and enhance resilience can diminish multiple risks simultaneously. Adaptation actions can also be mutually beneficial in more specific ways. Conservation of wetlands, for example, may serve both as a means of reducing climate risks for vulnerable species or ecosystems and of protecting coastal areas from erosion and flooding by providing a buffer area, while sequestering GHGs (Howard *et al.*, 2017). Making power grids more resilient can also help limit the potential adverse effects on communities, economic well-being, and health from extreme weather events ranging from freezing rain to heatwaves (Swiss Re, 2017). Targeting adaptation interventions that are mutually supportive across multiple areas of risk can increase the efficiency of these investments, enhancing their impact on risk reduction while sometimes conferring other benefits, such as supporting the United Nations' Sustainable Development Goals.

Adaptation actions, however, can interfere with one another, decreasing their effectiveness. Tensions within a specific area of risk can stem from multiple hazards. The agricultural sector, for example, faces the need to adapt to multiple climate-related stresses, including heatwaves, drought, heavy precipitation, and pests (Howden *et al.*, 2007; Porter *et al.*, 2014). This points to the need for a systematic approach that takes into account points of interaction.

3.3.2 Increasing Vulnerability and Exposure

Actions can increase, as well as reduce, vulnerability and exposure to climate change risks.

Reducing climate risks is accomplished through interventions that lessen either vulnerability or exposure to those risks, or both at once. In some cases, social, technological, and economic adaptation measures can increase risks by increasing vulnerability or exposure. These measures are *maladaptive* as they amplify the adverse consequences of climate change (Noble *et al.*, 2014). Dikes or levees intended to protect against flooding, for example, may encourage development in flood-prone areas, in part by creating an exaggerated sense of safety, leading to increased damage and harm should such defences fail. Similarly, the development of climate-resilient roads could lead to new development or settlement, which can be problematic if these are located in highly exposed areas (Noble *et al.*, 2014). Management actions for natural resources can also potentially increase threats. Forest management practices can amplify risks associated with wildfires (e.g., fire suppression contributing to fuel build-up) (Noss *et al.*, 2006; Flannigan, 2009; Wehner *et al.*, 2017), and maladaptive tillage methods can increase soil erosion, reducing long-term resilience to climate-related stresses, and potentially leading to carbon emissions from the soil (Lal, 2005; Silva-Olaya *et al.*, 2013; Krauss *et al.*, 2017). Maladaptive actions often occur because of existing institutional and economic incentives, or policies that fail to take into account climate change risks. Changing existing incentives to better account for the potential long-term costs of such actions can therefore reduce exposure and vulnerability. Consideration of potential negative impacts of new technologies, policies, or programs is also a component of mainstreaming climate adaptation.

Referring to attempts to prevent beach erosion without understanding natural cycles of beach retreat and expansion, Thomsen *et al.* (2012) indicate how maladaptation can emerge from actions failing to recognize the integrity and self-regulation of existing social-ecological systems. Actions can also be maladaptive if they facilitate adaptation for one group while impeding it for another, as may be the case in management interventions upstream and downstream on a shared river system (Noble *et al.*, 2014). Investments can also be maladaptive by constraining future adaptation opportunities; for example, the construction of new long-lived infrastructure such as a pipeline or a new highway without sufficient attention to climate-related stresses can constrain opportunities for adaptation in the future, and make future adaptation actions more costly (OECD, 2009; Eriksen *et al.*, 2011). Actions that increase GHG emissions are also regarded as maladaptive, as they increase the severity of climate-related hazards; some interventions, however, may be essential in some contexts even though they may also increase emissions (e.g., air conditioning).

3.3.3 Social and Technical Considerations

Social context and technical feasibility are both important factors for selecting adaptation measures.

Lessons from adaptation are often applicable across jurisdictions, and various mechanisms exist for technology transfer (UNFCCC, 2006). The opportunities for technology-based adaptation initiatives in Canada may be constrained in certain contexts, such as rural and remote areas with limited internet connectivity (OAG, 2018b). However, the social context should not be ignored; the IPCC (2014b) finds that "[r]ecognition of diverse interests, circumstances, social-cultural contexts, and expectations can benefit decision-making processes." The United Nations Framework Convention on Climate Change proposes a multi-staged approach to planned adaptation that evaluates potential adaptation measures in relation to cost, environmental sustainability, and the social and cultural context (UNFCCC, 2006). Stakeholders are to be involved in decision-making from the early planning stages; local buy-in is often vital to the success of an adaptation measure, as local groups may need to provide both expertise and implementation support. Ensuring local actors have the capacity to implement the adaptation measures is also critical (UNFCCC, 2006).

3.3.4 Windows of Opportunity

Adaptation potential changes over time, and particular periods provide critical windows of opportunity for adaptation.

The *Sendai Framework for Disaster Risk Reduction 2015 – 2030* (to which Canada is a signatory) includes a "build back better" principle among its priorities for action, which holds that disaster recovery offers an opportunity to improve future resilience (UN, 2015). Land-use planning and adjustments to construction standards are among the means to ensure assets are rebuilt to better withstand future events (UN, 2015). The Expert Panel on Climate Change Adaptation and Resilience Results underscored the importance of developing recovery plans in advance of disaster events in order to exploit the opportunity to build back better without slowing recovery efforts (EPCCARR, 2018).

This perspective can also apply to natural systems, where future climate projections can be factored into reforestation and conservation strategies. For instance, British Columbia's Climate-Based Seed Transfer Project is an adaptation strategy that determines suitable seeds for replanting based on expected future climate conditions (MFLNRO, 2016). Future wide-scale reforestation activities that occur in response to pest outbreaks and severe wildfire seasons can thus be more adaptive to future climates.

3.3.5 Co-Benefits

Adaptation options can have co-benefits for emissions reduction and other policy objectives and societal goals.

Adaptation actions can lead to co-benefits, arising from several different sources. In some cases, actions taken to adapt buildings and infrastructure to expected climate change impacts can also enhance their resilience to current climate-related threats (Klein *et al.*, 2014). Adaptation actions and planning can also have economic benefits through the provision of new goods and services and the creation of new markets (Klein *et al.*, 2014), for example through the need for building retrofits, the construction of new infrastructure, or through climate risk and vulnerability assessments. Finally, adaptation efforts targeted at reducing cross-cutting vulnerabilities are also often consistent with policy objectives such as poverty reduction, economic development, health interventions focused on at-risk populations, and the United Nations' Sustainable Development Goals (Klein *et al.*, 2014; UNFCCC, 2019).

3.4 UNDERSTANDING ADAPTATION POTENTIAL IN THE CONTEXT OF RISK

Plotting risk level against adaptation potential offers a richer understanding of each climate change risk area identified by the Panel in Chapter 2. Figure 3.3 illustrates that all of these areas are of significant concern and all have the potential for meaningful action to reduce the risks. The figure also reveals the significant variability in adaptation potential across risk areas.

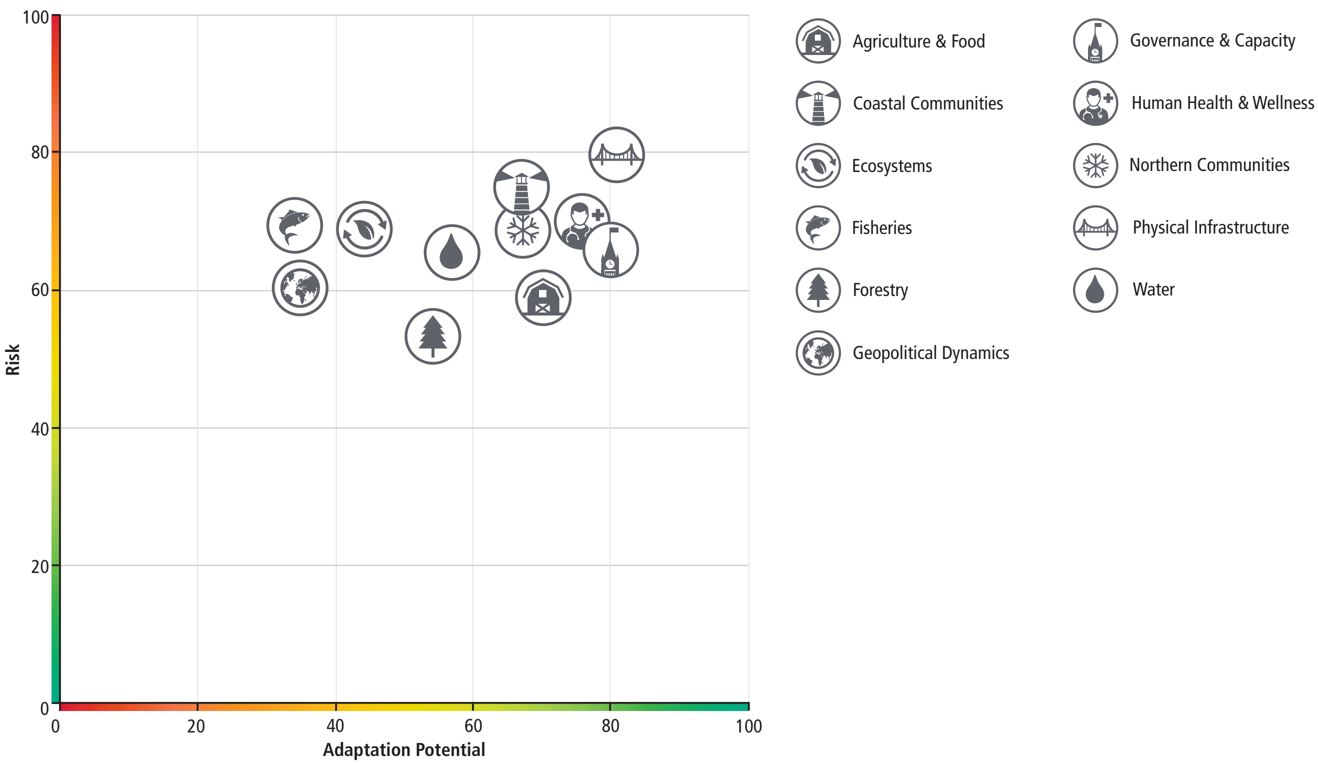


Figure 3.3

Panel Assessment of Risk and Adaptation Potential for Major Areas of Climate Change Risk

Risk level is a product of consequence and likelihood. The overall orientation of the response to managing different risks depends on risk level and adaptation potential. The Panel could not produce a defensible evaluation of the adaptation potential of the Indigenous ways of life risk area. This was due to the lack of Indigenous members on the Panel, and to limited inclusion of Indigenous knowledge in the assessment.

The Panel observed that risk areas that are plotted further to the right and to the top tend to be better understood, and there tends to be greater consensus on both the need for and the nature of adaptive responses. Significant and early investments in adaptation would help address these risk areas. In contrast, risk areas plotted further to the left and to the bottom tend to be more complex: there may be more inter-jurisdictional dimensions, more uncertainty, and less opportunity for effective human influence. In these areas, in addition to pursuing existing adaptation options, there is often a need for research to improve understanding of the risk area, investigation of new adaptation options, continuous monitoring of changes in the risk profile, and planning to cope where it is not possible to adapt to the climate change impacts.

The analysis summarized in this figure is necessary but not sufficient to identify key areas of federal concern. Government of Canada decision-makers need to filter this analysis through the lens of federal government mandates, policy priorities, and the needs of the public, particularly Indigenous Peoples. Some of these additional considerations are explored in Chapter 4.

4

Decision-Making and Federal Prioritization

KEY FINDINGS

- While decisions on action to manage climate change risk are often driven by perceptions of urgency, federal adaptation planning can also be informed by prioritizing the nature of the Government of Canada's involvement in each risk area, whether through coordination and collaboration, capacity building, or managing federal assets and operations.
- Federal climate change adaptation priorities can be identified based on the types of consequences and severity of the risks, the likelihood of such risks, the potential for adaptation, and the nature of the response measures required.

The federal government plays a role in virtually all policy domains implicated in climate change adaptation. Even in policy areas where there is clearly defined provincial/territorial/Indigenous authority based on the constitutional division of powers, the federal government is often active either through its spending power or function as a regulator and coordinator.[14] The nature of federal involvement and any associated activities vary considerably, often driven by individual departmental mandates. While these are important, the focus in this assessment is on climate change risks and adaptation actions that cut across multiple departments and agencies.

The Panel's charge included the following question: *How should [climate change] risks be categorized in order to support effective decision making and action?* While decisions on action required to reduce risk are often driven by perceptions of urgency, federal government planning and prioritization for adaptation to climate change risks need also to be informed by a comprehensive understanding of the nature of its role in each risk area. This ensures no major areas of risk are neglected, and that government resources are allocated appropriately.

4.1 CONTEXT FOR FEDERAL ADAPTATION DECISION-MAKING

4.1.1 Policy Frameworks

The *Federal Adaptation Policy Framework* and the *Pan-Canadian Framework on Clean Growth and Climate Change* govern climate change adaptation for the federal government.

The Panel considered existing frameworks to understand the context for federal climate change adaptation. The *Federal Adaptation Policy Framework* guides the Government of Canada's domestic adaptation activities, and is intended to encourage consideration of adaptation across federal processes. It focuses on mainstreaming adaptation efforts, knowledge creation and dissemination, and capacity development (GC, 2011). It also highlights the federal government's role in providing knowledge to other organizations in order to build understanding and enhance adaptive capacity (GC, 2011).

14. The *Constitution Act of 1982* sets out the fundamental legal basis for the division of powers in Canada between the federal and provincial/territorial governments (GC, 2012a).

The *Pan-Canadian Framework on Clean Growth and Climate Change* (Pan-Canadian Framework) represents a collective plan for the Government of Canada and provincial/territorial governments (excluding the Government of Saskatchewan) (GC, 2017a). It identifies new actions to enhance climate change resilience in the following areas:

- "Translating scientific information and Traditional Knowledge into action
- "Building climate resilience through infrastructure
- "Protecting and improving human health and well-being
- "Supporting particularly vulnerable regions
- "Reducing climate-related hazards and disaster risks"

The Panel notes that this approach tends to treat each of these areas independently and does not address the need to identify cross-cutting problems and solutions, nor does it include a focus on ecosystem impacts. Box 4.1 summarizes the many roles of the federal government in relation to disaster risk management, and considers the links between climate change adaptation and disaster risk response.

4.1.2 Current Challenges

Shortcomings have been identified with current federal approaches to managing climate change adaptation.

In 2017, the Commissioner for Environment and Sustainable Development (CESD) conducted an audit of federal progress on climate change adaptation (CESD, 2017). The audit identified the importance of ensuring federal assets and operations are resilient in a changing climate. The CESD found that there was a need for government-wide priority-setting and an action plan to advance implementation of the *Federal Adaptation Policy Framework*, as well as establishment of clear roles and responsibilities, and measuring and reporting. The audit found that only 5 of 19 departments and agencies reviewed had considered the risks of climate change in relation to departmental activities: Fisheries and Oceans Canada, Health Canada, Indigenous and Northern Affairs Canada, Natural Resources Canada, and Transport Canada. In response, Environment and Climate Change Canada committed to working with central agencies to provide additional guidance and support to other departments, and pointed to the Pan-Canadian Framework as the government's adaptation plan (CESD, 2017).

Box 4.1
Disaster Risk Management

The need for effective coordinated disaster prevention, mitigation, and response will grow as weather events become more severe and more frequent. In recent years, there has been growing emphasis on prevention and "building back better" in particular (i.e., avoiding or reducing risk through reconstruction) (UN, 2015; Henstra & Thistlethwaite, 2017). The federal government plays an important role in emergency preparedness and disaster response. It collaborates with other governments, as well as groups such as first responders and voluntary organizations (PS, 2019). While emergency response starts at the local level, local governments may request support from provincial and territorial governments, who may in turn request federal support as needed. This federal support may come in the form of logistics and coordination support, as provided through the Government Operations Centre, or financial support, as distributed through the Disaster Financial Assistance Arrangements (DFAA) program (PS, 2019). The average annual expenditures from the DFAA program between 2011 and 2016 were $360 million (PS, 2017). The Government of Canada provides compensation for damages not otherwise covered through insurance, as is often the case for flood damage; in one severe case, the Government of Canada paid $600 million for flooding in Alberta in June 2013 (PS, 2017), and accelerated claims for Employment Insurance for those unable to work because of the flooding (Finley, 2013). The federal government also plays an important role in emergency management in cases where the emergency affects multiple jurisdictions, when it affects federal assets and areas of responsibility, when it affects public confidence in the government, or when disaster events are deemed to be of national interest (i.e., "defence and maintenance of the social, political and economic stability of Canada") (GC, 2012b). In addition, the Canadian Armed Forces can be called to provide "aid of the civil power" when civil authorities are insufficient (JUS, 1985).

4.2 CATEGORIZING RISKS FOR DECISION-MAKING

Federal actions to respond to climate change risks fall under three broad areas: coordination and collaboration, capacity building, and federal assets and operations.

All 12 areas of risk identified by the Panel (Chapter 2) would benefit from additional risk-management actions by the federal government given the scale of potential negative consequences. However, adaptation actions will also be required through effective partnership involving all governments (federal, provincial/territorial, Indigenous, and local), the private sector, communities, and individuals, to ensure that the worst damages and greatest losses stemming from climate change are avoided. The nature of the Government of Canada's involvement differs across each risk area and is a function of the associated mandates of federal departments and agencies, of provincial/territorial, Indigenous, and local governments, and of actions undertaken outside of government. Supporting adaptation in the private sector is an appropriate role for the federal government insofar as it is important to the economy and society as a whole, and because businesses supply many essential services (NRT, 2012; Surminski *et al.*, 2018). The National Round Table on the Environment and the Economy identified five barriers to private sector adaptation that could benefit from government support: "vulnerability through interdependencies, lack of policy and regulatory support, gaps in information and tools to aid decision making, lack of financial incentives from government, and lack of shareholder and investor commitment and support" (NRT, 2012).

Capacity building may be a priority for some risks, while for others, the coordination and collaboration role may be dominant; yet in other cases, managing risks to federal assets and operations may be a first priority (Figure 4.1). In virtually all cases, however, the federal government will need to engage on multiple levels and will have more than one role to play in responding to these risks. This section articulates the Panel's understanding of these three main areas of intervention and provides examples of current activities that fall within each.

Each of these categories has implications for departments, expertise, resources, and nature of the response and can thus support decision-making — one effective way to characterize climate change risks, in the Panel's view, is by category of adaptation response required (e.g., information dissemination, capacity building, regulations). The Panel did not attempt to undertake any kind of gap analysis or offer commentary on areas of strength or weakness. These three categories are not always fully discrete; for instance, interdepartmental coordination may be required for effective program delivery. The Panel also underscores the importance of showing leadership by example through managing climate change risks to federal assets and operations.

4.2.1 Coordination and Collaboration

The pervasiveness, complexity, and interconnectedness of climate change necessitate concerted efforts to coordinate adaptation measures.

Adaptation is often appropriately delivered through an effective partnership involving all governments, the private sector, communities, and individuals. An overarching and important role for the federal government is to enable and empower this partnership.

Interdepartmental

The *Greening Government Strategy*, developed to support Canada's sustainability goals, includes the need to assess climate-related risks to federal assets, services, and operations and to ensure they are resilient to climate change (TBS, 2018a). The Treasury Board of Canada Secretariat itself recognizes its role in helping embed this coordination in its capacity as the lead department for the Greening Government Strategy, and as a central agency that oversees financial management (TBS, 2018b).

Effective adaptation often comprises a portfolio of actions, and does not necessarily sit within the mandate of a single federal department. Thus, government-wide efforts associated with climate change adaptation, included as part of an effective partnership, would also be beneficial. For example, the federal government provides essential services such as national security, border safety and security, marine safety, and social security, many of which are enabled by multiple departments and agencies, and all of which could be influenced by climate change impacts. There may be a further need to coordinate climate change adaptation policies with other policies that may unintentionally enhance or undermine exposure and vulnerability (e.g., land-use policies) or lead to maladaptation to climate change (e.g., certain coastal flood defences), in order to develop solutions that instead create co-benefits.

Domestic

Very few areas of climate change adaptation policy or action reside entirely within federal jurisdiction. Given the intersectionality and interdependence of climate risks, climate change adaptation will necessarily involve multiple

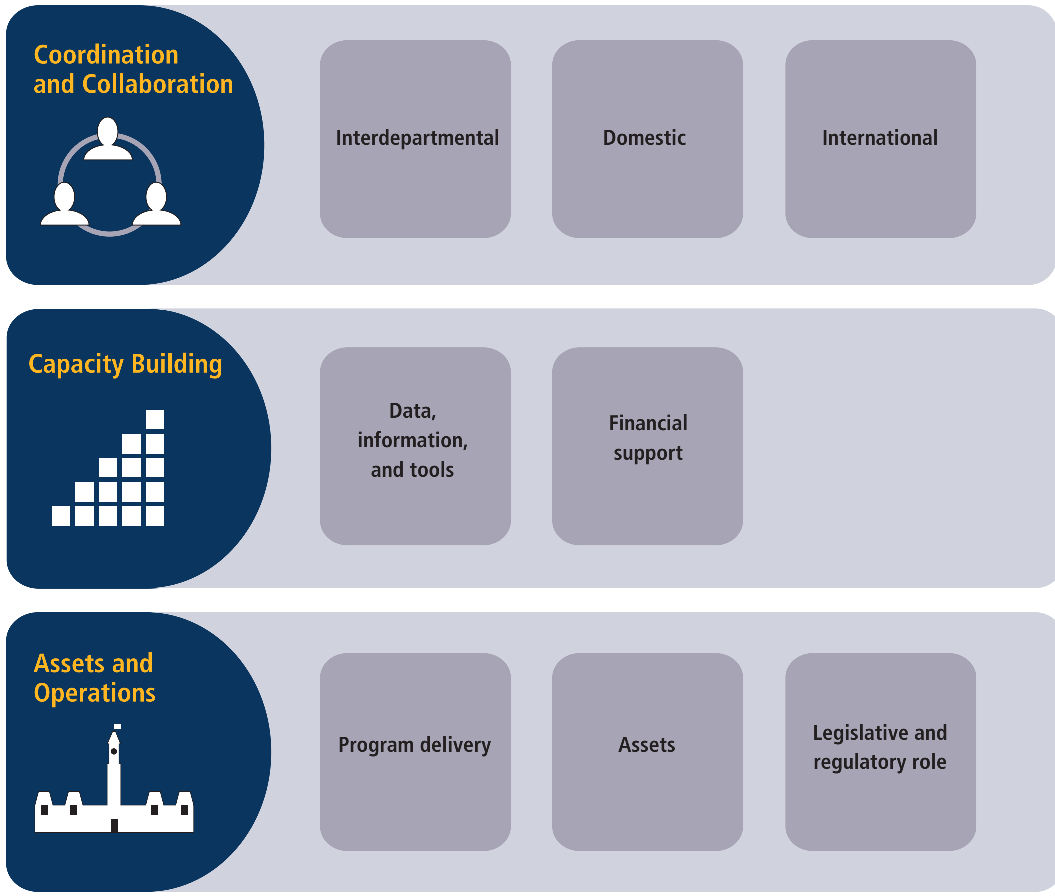


Figure 4.1

Three Categories of Federal Actions to Manage Climate Change Risks

Federal interventions to manage climate change risks fall into three broad categories. Coordination and collaboration may be required across federal departments, across domestic actors, and internationally. Capacity building encompasses provision of data, information, and tools as well as financial support. Federal assets and operations include program delivery, protection and adaptation of federal assets, and the federal government's legislative and regulatory role.

governments, as well as the private sector, communities, and individuals; associated mechanisms for coordinating these efforts are crucial (Corfee-Morlot *et al.*, 2009). The need for coordination and collaboration is further compounded by the fact that governments often find themselves working in concert in areas where there is shared jurisdiction (e.g., agriculture) or where jurisdiction was not clearly established by the Constitution. The Pan-Canadian Framework is the primary vehicle for coordinating efforts by the federal, provincial, and territorial governments. Annual synthesis reports on the framework's implementation capture efforts within and across jurisdictions.

The federal government has also committed to implement the Truth and Reconciliation Commission's Calls to Action (CIRNAC, 2019a). The TRC (2015) states that "reconciliation is about establishing and maintaining a mutually respectful relationship between Aboriginal and non-Aboriginal peoples in this country. In order for that to happen, there has to be awareness of the past, an acknowledgement of the harm that has been inflicted, atonement for the causes, and action to change behaviour." The Office of the United Nations High Commissioner for Human Rights calls for recognition of the obligations of *duty-bearers* to respond to climate change in a way that fulfills the human rights of *rights-holders* (OHCHR, 2010). This includes the right to meaningful and informed participation, in which groups that stand to be affected by climate change are given a voice in decisions (OHCHR, n.d.). Given that a changing climate may compromise the ability of Indigenous Peoples to exercise some of their rights (CIER, 2006), coordination of efforts with Indigenous governments is also essential (Box 4.2).

Box 4.2
Coordination with Indigenous Governments

The legal and policy basis for coordination between the Government of Canada and Indigenous Peoples on climate change is continuing to evolve. The government's recognition of Indigenous Peoples' rights to self-determination and self-government; to their lands, territories, and resources; and to participation in decision-making affecting those rights (JUS, 2018), all have far-reaching implications for managing climate change impacts (among other things). The federal government recently established a set of principles aimed at informing its efforts to establish "nation-to-nation, government-to-government, and Inuit-Crown relationships," and these principles can be expected to guide future engagement and cooperation with Indigenous Peoples on climate change adaptation (JUS, 2018). Chamberlain (2012) has also examined whether the Crown's fiduciary relationship with Indigenous Peoples could be relevant for addressing some aspects of climate change.

For the development of the 2016 *Pan-Canadian Framework on Clean Growth and Climate Change*, four federal-provincial-territorial working groups were used as one means for incorporating Indigenous knowledge and considerations. Following the signing of the agreement, the Prime Minister and the leaders of the Assembly of First Nations, the Inuit Tapiriit Kanatami, and the Métis National Council made joint commitments and developed bilateral tables to build "a structured, collaborative approach for ongoing engagement with Indigenous Peoples in the implementation [of the framework] and on broader Indigenous-specific clean growth and climate change priorities" (ECCC, 2018).

However, cooperation between the federal government and Indigenous governments is made more difficult by the legacy of colonialism, power imbalances, and a lack of resources to enable trust and meaningful engagement (CCA, 2019), and recent initiatives have sometimes been criticized as insufficient. For example, the process used by the federal government to develop the new principles governing relations with Indigenous Peoples was criticized by national Indigenous leaders (e.g., AFN, 2017a). King and Pasternak (2018) state that, "[w]hile the Ten Principles have supporters among some First Nation analysts, and they do represent a shift in rhetoric from previous governments, they nonetheless emphasize the supremacy of the Canadian constitutional framework and constrain the possibilities for self-determination among Indigenous peoples."

The federal government can enable and empower other levels of government, the private sector, communities, and individuals by creating a cooperative environment. Natural Resources Canada hosts the Adaptation Platform, a "network of networks" composed of federal departments, provincial/territorial governments, national Indigenous organizations, private sector and not-for-profit organizations, and researchers (NRCan, 2018a). The Platform is intended to pool resources to develop and disseminate new information and tools, and to implement adaptation actions. Federal coordinating efforts may focus on establishing joint priorities, coordinating investments, planning emergency response, or measuring adaptation progress (e.g., EPCCARR, 2018). In some instances, inter-jurisdictional harmonization will be required for efficient adaptation. Managing coastal flood risks is one such area, as it may implicate local, Indigenous, provincial/territorial, and federal governments, port authorities, and public and private land-holders. Adaptation efforts by any one of those groups may enhance or undermine adaptation efforts pursued by the other groups; shared strategies may therefore be necessary.

International

The interconnected and global nature of many climate-related risks calls for internationally coordinated adaptation responses in many areas. The water bodies shared between Canada and the United States are one such instance, and the International Joint Commission has been considering the impacts of climate change on the Great Lakes through its International Watersheds Initiative (IJC, n.d.). The Panel notes the opportunity for the federal government to champion internationally the importance of Indigenous knowledge in informing climate change adaptation, but that more action is required to demonstrate leadership at the domestic level. The federal government also plays a significant role in supporting international research activities and partnerships, including for example international cooperation in Arctic science research (GC, 2018f). Moreover, international coordination is necessary to support Canada's participation in multilateral processes and honour commitments made to international agreements, including the *Sendai Framework for Disaster Risk Reduction 2015 – 2030* (UN, 2015), the *Paris Agreement* (UNFCCC, 2015), and the

United Nations' *2030 Agenda for Sustainable Development* (UN General Assembly, 2015); consistent with these, international coordination is also called for to support climate change adaptation in poorer countries. Commitments made under these three international agreements, among others, call for careful alignment to ensure that efforts to respond to these issues are mutually reinforcing and not acting independently or at counter purposes.

4.2.2 Capacity Building

The federal government is often best positioned to provide resources that can build the adaptive capacity of other actors.

Data, Information, and Tools

The Government of Canada conducts climate modelling, tracks climate trends and variability, advances the science of climate change, leads periodic national climate change assessments, and contributes to the IPCC; Environment and Climate Change Canada employs the largest group of climate scientists in Canada (EC, 2015; GC, 2018b). As such, the federal government is a unique source of data and expertise, and can exploit economies of scale in the generation and dissemination of information and research that can support evidence-informed choices about managing climate change risks (GC, 2011). The recently established Canadian Centre for Climate Services provides publicly accessible data, information, and resources along with a support desk to field questions (GC, 2019b). Projections of future climate conditions and other supportive data and information offer value to a range of decision-makers. Cities may use this information to increase the climate resilience of their infrastructure; design and deliver green infrastructure; and protect, restore, and install natural infrastructure. Forestry companies and other land-owners can make better-informed decisions about tree planting and harvesting plans for the future. Individuals can better weigh adaptation actions they can take to manage flood risks through home purchases and retrofits.

The federal government may also offer decision-support tools to inform climate actions, such as the compendium of tools and resources designed to assist Canadian municipalities to advance climate action (Richardson & Otero, 2012). The Standards Council of Canada's Northern Infrastructure Standardization Initiative has developed five new national standards for northern infrastructure, and additional work is ongoing (SCC, 2018). The government has provided funding to support decision-making tools such as Ouranos' *A Guidebook of Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions*, and the International Institute for Sustainable Development's ADAPTool, which can be used to screen new and existing government policies for their resilience to climate change (NRCan, 2018c).

The federal government also supports local monitoring of climate change in Indigenous communities and bridging "Traditional Knowledge and science to build a better understanding of impacts and inform adaptation actions" (GC, 2011).The potential is there for the federal government to support Indigenous Peoples as they renew Indigenous knowledge to prepare for and adapt to climate change, as well as to protect Indigenous ways of life. Some of this is already occurring through initiatives such as ArcticNet, which has enabled collaboration among Inuit organizations, academic researchers, industry, and governments (ITK, 2016). The national Inuit organization Inuit Tapiriit Kanatami participates in ArcticNet governance (ITK, 2016). Another example is the federal government's Indigenous Community-Based Climate Monitoring Program, which is designed to support community-led monitoring efforts and bridge Indigenous knowledge with science-based information (CIRNAC, 2019b).

Financial Support

Federal funding can support climate change adaptation across Canada through grants and contributions programs aimed explicitly at funding climate change adaptation; activities that mainstream climate change adaptation-related considerations into broader programs; and transfer programs that strengthen the social safety net, thereby reducing vulnerability. Examples of financial contributions include support for the development of climate-resilient infrastructure through the $2 billion cost-shared Disaster Mitigation and Adaptation Fund, funding adaptation projects in the North, as well as projects for First Nations south of the 60th parallel (CIRNAC, 2018a, 2018b; ECCC, 2018; Infrastructure Canada, 2018). Others include funding for the Adaptation Platform, and support for research initiatives by the Canadian Institutes of Health Research and the Natural Sciences and Engineering Research Council, among others (CIHR, 2018; NRCan, 2018a; NSERC, 2018).

4.2.3 Federal Assets and Operations

Safeguarding public assets and ensuring the ongoing ability to deliver public services in a changing climate are key areas of federal responsibility.

Program Delivery

Each federal department and agency is expected to "apply its experience in risk management to the climate change issues that could affect its continued ability to deliver on its mandate" (GC, 2011). In the Panel's view, compliance with legal obligations, and with domestic and international commitments, rests within this category. Departmental management of climate-related risks entails anticipating and planning for disruptions that could occur or intensify in a changing climate (including worst-case scenarios), and establishing climate-resilient processes and operations. In Transport Canada's review of climate risks, for example, the department identified risks to its compliance and oversight activities, including the need to modify the system governing access to Arctic waters to reflect changing sea-ice conditions, and potential increases in demand for monitoring and inspection in the North (TC, 2012).

Mainstreaming adaptation into decision-making is essential, and is already underway in some instances. Federal infrastructure funding proponents are now being required to demonstrate adaptation planning for the lifecycle of investments (GC, 2018c). Effective mainstreaming will sometimes require interdepartmental coordination to ensure efforts are mutually supportive rather than conflicting. Future reviews and developments of national strategies will have to consider the costs associated with climate change, which are likely to be significant over the next 20 years (Section 2.2).

Assets

Maintaining the value and functioning of federal assets in a changing climate and enhancing the resilience of these assets are also among the responsibilities of the federal government. It owns or leases over 20,000 properties representing over 40 million hectares of land (TBS, 2018c). As of March 31, 2018, the Government of Canada's tangible capital assets (including land and buildings) totalled $73.8 billion (GC, 2018e). Like infrastructure more generally, many of these assets will face some degree of vulnerability or risk associated with climate change, be it due to thawing permafrost, susceptibility to flooding, or exposure to sea-level rise. For example, Transport Canada's review of climate risks identified vulnerable assets, including two northern airports experiencing permafrost thaw, and nine ports that are highly sensitive to sea-level rise (TC, 2012).

Legislative and Regulatory Role

Governments can enhance policy alignment and support mainstreaming by revisiting existing laws and regulations with an eye to climate change impacts and adaptation, and prioritizing the required revisions, as well as applying this lens to new laws and regulations (Gov. of QC, 2012). The National Research Council is conducting research and analysis to factor climate resilience into revisions to building and infrastructure design codes (NRC, 2018). The *Canada Business Corporations Act* has been identified as another potential lever that could be adjusted to call for financial disclosure of climate change-related risks, consistent with changes made in the United Kingdom and European Union (Bak, 2019). The Bank of England is considering stress-testing U.K. banking institutions to ensure the sector is resilient to climate change (BoE, 2018).

4.3 SELECTING ADAPTATION ACTION PRIORITIES

Federal climate change adaptation action priorities can be identified based on the types of consequences and severity of the risks, the potential for adaptation, and the nature of the response measures required.

Effective climate change adaptation includes making choices, both in terms of identifying priorities and selecting response measures (CESD, 2017). The process for prioritizing federal adaptation actions may differ from the process used to assess risk severity or likelihood. Initiatives such as the *UK Climate Change Risk Assessment 2017* suggest that prioritization take into account additional factors such as adequacy of current strategies or policies for managing risks and the adaptive capacity of the system or systems at risk (ASC, 2016). The top risks may not necessarily be the highest priorities for additional action by the federal government if it is believed that these risks are being managed appropriately (or do not fall under federal responsibility). Other risks may be high priorities if urgent action by the federal government is needed, or if existing information is inadequate. Appropriate governance of this prioritization will enhance the legitimacy of the results.

All 12 risk areas would benefit from dedicated risk-management actions by the Government of Canada; however, the urgency and nature of the actions required vary across risks. In recognizing scarce resources (including limited knowledge and capacities) and the reality that it will rarely be acting alone to address any risk area, the Government of Canada can prioritize the nature of its involvement in each risk area, be it through coordination and collaboration, capacity building, and/or managing government assets and operations. This set of categories is intended to complement and support the *Federal Adaptation Policy Framework*, which identified the following prioritization criteria: nature of the impacts and vulnerability, appropriateness of federal action, mainstreaming ability, and collaboration potential (GC, 2011).

The Panel identified a series of factors worth considering when the federal government assesses the need to engage in each of the three categories of intervention (Figure 4.2). Working through these considerations, the federal government can develop a profile for each risk area to guide its response. In most instances it may need to play a role in multiple areas. Given the nature and breadth of risks posed by climate change, the federal government could benefit from a framework that supports departmental decision-making while also coordinating horizontal prioritization and collaboration across departments and agencies.

An analysis of these factors could be implemented in the Canadian context in many ways. The process of evaluating the factors should be linked to a consideration of how results would inform decision-making within the federal government. For example, for informing resource allocation, care needs to be taken that the results are consistent with the needs of decision-makers in central agencies involved in budget decisions. Where the goal is to inform prioritization of roles and activities across (or within) departments, the information needs of decision-makers are quite different and the process and outputs should be adapted accordingly.

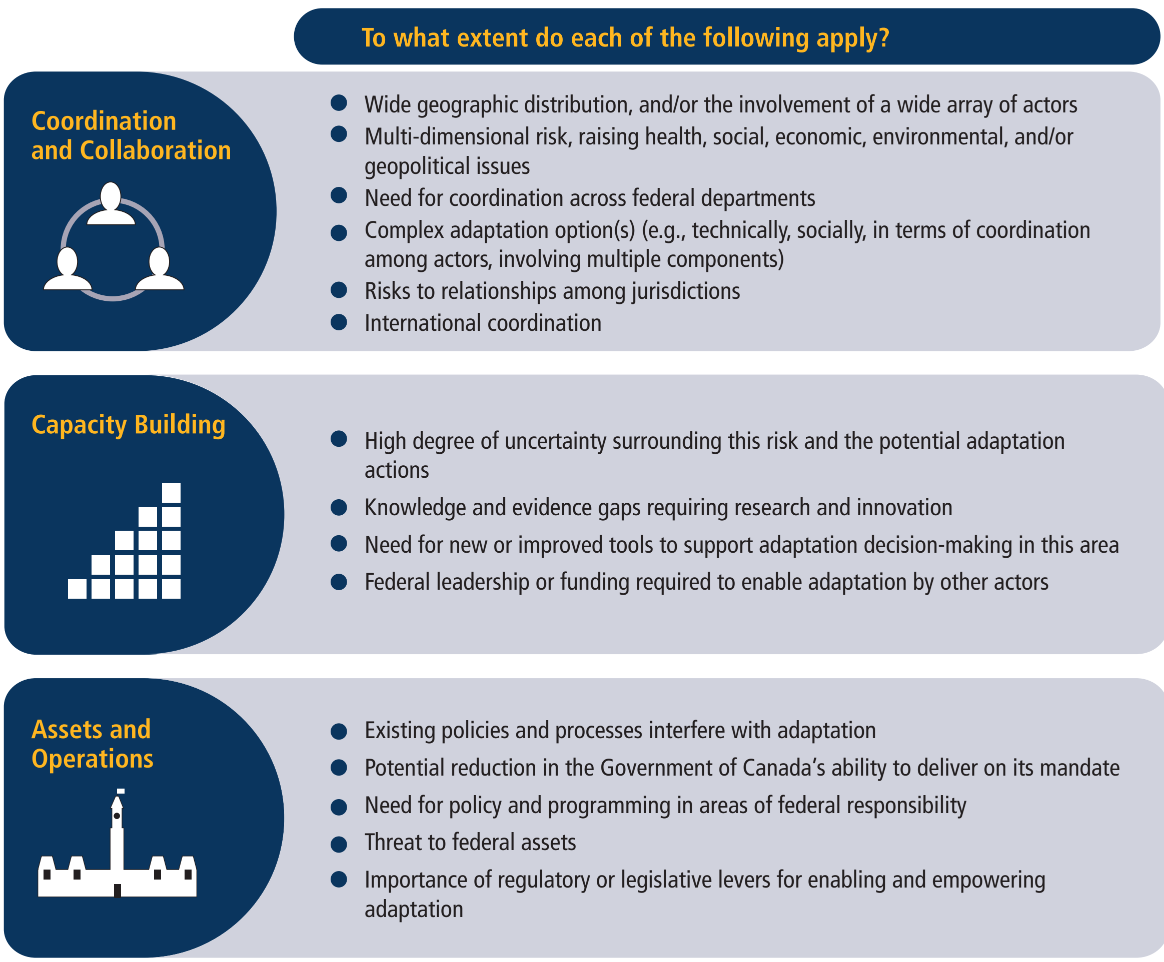


Figure 4.2

Factors Influencing the Need for Federal Action

The extent to which the federal government has a role to play in supporting adaptation via coordination, capacity building, and federal assets and operations can be evaluated against the factors set out above.

5 Conclusions

5.1 RESPONSE TO THE CHARGE

Assessments of the risks posed by climate change are subject to many sources of uncertainty. Climate projections and modelling results provide an envelope of possible futures associated with different GHG emissions trajectories, but the exact path of global emissions and the full implications for the climate, combined with other natural and anthropogenic processes, remain unknown. Data limitations and evidence gaps hinder understanding of many likely impacts of a changing climate, especially where interactions among economic, natural, and social systems could lead to cascading consequences. Tipping points in natural systems and climate dynamics could lead to runaway climate change and impacts impossible to reverse on the scale of centuries or millennia. Further research is essential for continuing to improve emissions and climate scenarios, and to enhance the robustness and relevance of climate risk assessments for Canada and the world. This absence of certainty, however, should not serve as a barrier to either climate change risk assessment or adaptation action.

Climate change is very likely to cause significant negative impacts across many natural and human systems in Canada over the next 20 years. Government-wide prioritization will help clarify the best options for using limited resources, and risk assessments can help inform such prioritization. The Panel identified 12 major areas of risk, using the criteria of consequences (magnitude) and likelihood: agriculture and food; coastal communities; ecosystems; fisheries; forestry; geopolitical dynamics; governance and capacity; human health and wellness; Indigenous ways of life; northern communities; physical infrastructure; and water. Criteria that are useful in the assessment of the relative impact of risks from a changing climate include: (i) impacts on the environment and natural systems; (ii) impacts on the economy; (iii) impacts on society and culture; (iv) impacts on human health and wellness; and (v) impacts on geopolitical dynamics and governance.

The Panel concluded that risks at the national level are most acute in six areas: physical infrastructure, coastal communities, northern communities, human health and wellness, ecosystems, and fisheries. However, all 12 risk areas have the potential to cause major harm in the coming decades. None of the major areas of climate change risk reviewed by the Panel can be ignored or deferred. The Panel also underscored risks to Indigenous ways of life, and emphasized the need for a more inclusive and reflective process of risk assessment and prioritization working alongside Indigenous Peoples in a spirit of reconciliation. The federal government, along with other levels of government, the private sector, communities, and individuals, will have to consider the systemic impacts of multiple risks on particular regions, sectors, and systems on an ongoing basis in order to ensure that they are sufficiently resilient to Canada's changing climate. Additional progress on GHG emissions mitigation is also essential as an ongoing, long-term strategy to reduce all climate change risks.

Adaptation measures have the potential to offset many of the potential negative impacts and costs associated with these risks if implemented in a timely fashion, but this potential varies widely across areas of risk. The six areas of risk identified as having the highest adaptation potential are: physical infrastructure, governance and capacity, human health and wellness, agriculture and food, coastal communities, and northern communities. The Panel chose not to present a specific rating of the adaptation potential of Indigenous ways of life, as was done for the other risk areas, due to the lack of Indigenous members on the Panel, and limited inclusion of Indigenous knowledge in the assessment.

The Panel also considered how best to categorize risks in order to support effective decision-making and action. While processes to decide what action is required to manage risk are often driven by perceptions of urgency, federal government planning and prioritization for adaptation to climate change risks could also be served by a comprehensive understanding of the nature of its role in each risk area, whether it be coordination and collaboration, capacity building, or managing government assets and operations. This ensures no major areas of risk are neglected, and that government resources are allocated based on a detailed assessment of adaptation roles and needs, acknowledging that the federal government will rarely be acting alone in managing these risks.

5.2 FINAL REFLECTIONS

The need for action on climate risk is increasingly urgent. This assessment represents a high-level approach to prioritizing climate change risks facing Canada, and more detailed approaches and results may evolve with future efforts. The set of risks that has emerged from this process is undoubtedly paramount for Canadian society. However, existing knowledge gaps and challenges, together with limited resources, constrained the Panel's ability to conduct a national risk prioritization exercise reflective of the geography of Canada, diversity of the population, and the values of people in Canada. Structured, well-resourced, inclusive, and regularly repeated national (and regional) climate change risk assessments in Canada could enhance their transparency, legitimacy, and authority going forward.

Importantly, this Panel was limited in its ability to draw from Indigenous knowledge, which would require much broader involvement from Indigenous experts. The Panel believes it is fundamental for governments in Canada to work together with Indigenous Peoples to develop socially, culturally, and economically relevant assessments and adaptation practices. A deeper exploration of risks facing Indigenous Peoples in Canada is warranted and is in fact paramount to good process in a time of reconciliation.

Other countries base their national risk assessments on a more exhaustive evidence-gathering and review process. Developing a formal evidence report to serve as a foundation for future risk assessments would also enhance the rigour of the process, especially if this process involved Indigenous Peoples and reflected Indigenous knowledge. In Canada's case, this might be achieved by formally linking the federal government's risk assessment to the comprehensive reviews of climate change impacts already periodically undertaken by the Government of Canada.

A more in-depth assessment process with greater resources would facilitate more specificity in the analysis of actual risks, which would likely allow greater precision in the estimation of their potential consequences and likelihoods. National risk assessments could also enable and encourage other jurisdictions within Canada to establish complementary prioritization processes. Ongoing learning is critical to this work so that future assessments include emerging knowledge of impacts and adaptation from both science and Indigenous knowledge traditions, include process refinements that reflect what has been learned from Canada and internationally, and benefit from the results of monitoring and evaluation programs that track adaptation progress.

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Glossary

Term	Definition
Adaptation	The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (Oppenheimer *et al.*, 2014).
Adaptation Potential	A measure of the capacity of an individual, community, or system to adjust to actual or expected climate and its effects. As used in this report, it was assessed as the extent to which potential damages or losses from climate change could be avoided with an appropriate combination of adaptation actions and responses (Expert Panel).
Adaptive Capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (Oppenheimer *et al.*, 2014).
Autonomous Adaptation	Adaptation that occurs in the absence of deliberate or planned efforts to respond to changing climate conditions. Many natural systems adapt to changing climate conditions based on their innate structure and function. These types of adaptation can also be considered reactive as they occur only in response to climate conditions as they occur (adapted from Smit and Wandel, 2006).
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (Oppenheimer *et al.*, 2014).
Hazard	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts (Oppenheimer *et al.*, 2014).
Impacts	Effects on natural and human systems. The term *impacts* is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system (Oppenheimer *et al.*, 2014).
Planned Adaptation	Deliberate, intentional actions taken to facilitate climate adaptation (e.g., the construction of natural wetlands adjacent to a new subdivision to mitigate flooding during extreme rainfall events). Planned adaptation actions can also be anticipatory rather than reactive, in the sense that they can be taken based on expected climate conditions or changes in the future (adapted from Smit and Wandel, 2006).
Resilience	The capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure while also maintaining the capacity for adaptation, learning, and transformation (Oppenheimer *et al.*, 2014).
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (Oppenheimer *et al.*, 2014).
Sensitivity	The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damage caused by an increase in the frequency of coastal flooding due to sea-level rise) (Oppenheimer *et al.*, 2014).
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (Oppenheimer *et al.*, 2014).
Watching Brief	A watching brief is a mandate to check on and provide reports about what is going on with respect to a particular situation, sector, issue, etc. (Cambridge English Dictionary, 2019).

Appendix — Panel Risk Assessment Methods

The Panel developed its risk assessment methods based on the requirements of the project, as stipulated by the Sponsor, and was informed by similar initiatives undertaken in other jurisdictions. This Appendix describes these methods, including the processes used to identify and assess climate risks.

A.1 ASSESSMENT PROCESS OVERVIEW

Following clarification of its scope (Section 1.2), the Panel divided the assessment process into three main phases:

- Phase 1: Evidence gathering and risk identification
- Phase 2: Risk assessment
- Phase 3: Report drafting, review, and publication

A.2 EVIDENCE GATHERING AND RISK IDENTIFICATION

A.2.1 Evidence Gathering

Literature reviews, workshop outcomes (including both quantitative risk rankings and shared insights), and the Panel's own knowledge and expertise constituted the key sources of evidence incorporated into this first phase of the process.

Approximately two and a half months were allotted to evidence gathering, during which time the Panel and CCA staff gathered and reviewed existing studies relevant to the identification and assessment of climate risks facing Canada. Existing syntheses of evidence on climate impacts in Canada and North America (NRT, 2010; Romero-Lankao *et al.*, 2014; Warren & Lemmen, 2014b) were prioritized given the accelerated timeframe and available resources. The Panel commissioned a dedicated review of these documents and other academic studies to extract relevant information on risks it identified. In addition, the Panel continued to incorporate further evidence (in the form of new studies and additional references) into its deliberations throughout the study process.

An expert workshop also constituted one of the main sources of evidence. This workshop was held in Montréal in October 2018, and included the participation of 17 experts (plus Panel members) on various aspects of climate change impacts and adaptation. Designed to elicit insights and opinions on the climate change risks facing Canada, workshop discussions were facilitated through the use of group decision support software (GDSS) and an experienced facilitator from the Queen's Executive Decision Centre. Instead of relying on traditional tools such as flip charts or whiteboards, participants engaged with the facilitator and each other by entering ideas on laptops. Ideas were shared, merged, edited, and reorganized as needed. The group also used the laptops to vote on ideas or score risks, with the system collecting and ranking the results. This system facilitated several rounds of assessment of risks and adaptation potential, interspersed with critical discussion and debate.

A.2.2 Risk Identification

The first phase of the assessment also included initial work on risk identification. After establishing the context, the next step in risk assessment is the identification of risks (AGO, 2006; Bowyer, 2014; GRC, 2015; CoastAdapt, 2018). Building on earlier reviews of climate change impacts (NRT, 2010; Romero-Lankao *et al.*, 2014; Warren & Lemmen, 2014b), the Panel and CCA staff developed an initial list of 57 climate risks facing Canada. A subcommittee of the Panel was then tasked with refining this list. Some risks were amalgamated or grouped by this subcommittee, based on the systems at risk, while others were eliminated as they were not considered to be significant to Canada when considered at the national scale. (For a discussion on what the Panel means by national scale, see Section 1.2.3). The result was a list of 22 climate change risks, and these formed the basis of discussion at the workshop (Table A.1). However, based on feedback from participants, the Panel determined that the risks could be further narrowed and amalgamated into 12 main areas of climate risks facing Canada. These are listed in Table 2.1 and were used by the Panel as it proceeded with Phase 2 of the assessment.

Table A.1
Climate Change Risks Facing Canada

1	New and/or increasing threats to **flora and fauna**, including reduced viability of current species at risk and Arctic/alpine species, due to invasive species, shifting species distributions, and changing ecological and environmental conditions.
2	Declining **ecosystem resilience** due to decreasing biodiversity, changing ecological conditions, and shifting species distributions.
3	Declining ability of natural systems to provide **ecosystem services** such as erosion prevention and water filtration due to increasing environmental stresses.
4	Declining (or less regular) **water supply** for communities (including industry and utilities) due to changing precipitation patterns, melting glaciers, diminishing snowpacks, and earlier or more variable spring runoff.
5	Increasing incidence of adverse **health impacts**, including physical and mental health conditions and loss of life caused by extreme weather events, lower ambient air quality (e.g., due to wildfire smoke), and increasing ranges of vector-borne pathogens.
6	Increasing damage to **infrastructure** from extreme weather events, such as damage to homes and buildings from heavy precipitation events, high winds, and flooding; increased probability of power outages and grid failures; and an increasing risk of cascading infrastructure failures.
7	Increasing damage to **coastal infrastructure, property, and communities** from gradual inundation and coastal erosion due to **sea-level rise**.
8	Increasing damage to **northern communities and infrastructure** (e.g., buildings, roads, pipelines, power lines, airstrips) and reduced or disrupted access to communities and facilities due to thawing permafrost, warmer winter temperatures, increased snowfall, more frequent mid-winter freeze-thaw cycles, and earlier spring onset.
9	Declining opportunities for practising **Indigenous ways of life and cultural activities** due to changing weather patterns and environmental conditions, more frequent extreme events, and associated impacts on safety, food security, communities, traditional knowledge, language, and culture.
10	Adverse impacts on **agricultural crops** and the agricultural sector due to higher temperatures, increased frequency and/or severity of droughts, increasing frequency and/or severity of storms, heavy precipitation events, salinization of soils and groundwater due to sea-level rise, and increasing range of invasive species and/or pests.
11	Declining **forest health** and lower production of **timber and forest products** due to changing weather patterns (e.g., increased incidence of drought, wildfires, insect infestation), extreme weather events, and increasing range of invasive species and/or pests.
12	Declining **fish stocks** and less productive/resilient **fisheries** due to changing marine and freshwater conditions including warmer waters, lower water levels, flooding, ocean acidification, changing current patterns, poor water quality due to warmer conditions, invasive species, and pests.
13	Negative impacts on **tourism** and the tourist industry due to various climate-related impacts including: shorter winter seasons, less snowfall, more frequent freeze-thaw cycles, wildfires and wildfire smoke in summer, lower water levels in lakes and rivers, and compromised water quality due to low and warm water conditions.
14	Increasing frequency of disruptions to domestic **supply chains and transportation systems** due to heatwaves, low water levels in navigable waterways, heavy precipitation events and mudslides, and other climate extremes.
15	Increasing risk to **Arctic communities and public safety** stemming from heavier marine traffic and the potential for more frequent marine accidents due to the opening of the Northwest Passage as a result of reduced summer sea-ice extent.
16	Increasing pressure/costs on governments to provide **crop insurance, disaster relief, and social services** related to extreme weather events and slow-onset climate impacts (e.g., permafrost thaw, coastal erosion).
17	Increasing risk of disruptions to **global food production** and associated increases in food prices and food insecurity due to extreme weather events and pest proliferation.
18	Increasing incidence of disruptions to **global supply chains and international trade** due to extreme weather events in Canada and in other countries.
19	Increasing **international migration** and associated political, social, and economic stresses due to climate-related events such as droughts, major storms, and flooding.
20	Increasing prevalence of **political tension and social conflict** over climate-affected resources (e.g., water) in North America and globally, due to changing climate and environmental conditions and extreme weather in Canada and in other countries.
21	Heightened security and geopolitical tensions over **Arctic sovereignty and resources** due to declining sea-ice coverage, the opening of the Northwest Passage, and increased interest in Arctic resource development.
22	Increasing need for **humanitarian assistance and foreign aid** in other countries due to climate-related crises such as droughts, extreme heat, and floods resulting in food and water shortages and loss of life and livelihoods as well as ecosystems.

A.3 RISK ASSESSMENT

A.3.1 Workshop Assessment Process

The Panel adopted a semi-structured process for assessing risks, consisting of two main stages. In the first stage, the workshop provided an opportunity for a diverse group of experts to discuss and assess climate-related risks facing Canada. Aided by the GDSS, these discussions allowed participants to individually assess risks based on a structured rating scale taking into account multiple types of impact (e.g., economic impacts and costs, land area affected, human health and wellness impacts, environmental impacts), and then explore and validate these ratings as a group. The workshop used iterative rounds of assessment, discussion, and reassessment through a process similar to the Delphi method, a widely used methodology for collecting and aggregating expert opinion (Pill, 1971; Ven & Delbecq, 1974; Adler & Ziglio, 1996; Hsu & Sandford, 2007). In this case, participants went through three iterations of individual risk rankings and group discussion: (i) prior to the workshop (through an online survey disseminated to participants in advance), (ii) using the GDSS early in risk discussions (but after having reviewed the results from the online survey), and (iii) using the GDSS at the conclusion of the discussions. Workshop participants were provided with a structured, four-point scale for assessing the severity of the risks (Table A.2).

Similarly, the adaptation potential of the risks was assessed twice using a structured, four-point scale (Table A.3): first, through the initial online survey prior to the workshop, and then again at the close of discussions.

Table A.2

Workshop Risk-Rating Scale and Guidelines

Rating	Guidelines
Very High	Extreme damage and disruption or foregone opportunities: • $ billions of annual costs, damages, or losses, and/or • Thousands of km^2 of land lost or irreversibly damaged, and/or • Millions of people affected, hundreds of deaths, or hundreds of people irreversibly harmed, and/or • Major, widespread, and irreversible changes to natural assets or ecosystems and their associated goods and services.
High	Major damage and disruption or foregone opportunities: • $ hundreds of millions of annual costs, damages, or losses, and/or • Hundreds of km^2 of land lost or irreversibly damaged, and/or • Hundreds of thousands affected, dozens of deaths, or hundreds of people irreversibly harmed, and/or • Major, widespread changes to natural assets or ecosystems and their associated goods and services.
Medium	Moderate damage and disruption or foregone opportunities: • $ tens of millions of annual costs, damages, or losses; • Tens of km^2 of land lost or irreversibly damaged, other reversible/localized damage occurs, and/or • Thousands affected, a few deaths, or a few people irreversibly harmed, and/or • Significant changes to natural assets or ecosystems and their associated goods and services.
Low	Minor damage and disruption or foregone opportunities: • Less than $ tens of millions of annual costs, damages, or losses, and/or • Little land area affected or irreversibly damaged, only reversible/localized damage occurs, and/or • Hundreds affected, possibly a few deaths, or a few people harmed, and/or • Minor, gradual changes to natural assets or ecosystems and their associated goods and services.

Adapted from Warren *et al.* (2016)

Table A.3
Workshop Adaptation Potential Rating Scale and Guidelines

Rating	Guidelines
Very High	Nearly all (>75%) potential damages or losses can be avoided with an appropriate combination of adaptation actions and responses.
High	Most (>50%) of potential damages or losses can be avoided with an appropriate combination of adaptation actions and responses.
Medium	Some (between 25 and 50%) of potential damages or losses can be avoided with an appropriate combination of adaptation actions and responses.
Low	Little or none (<25%) of the potential damages or losses can be avoided with an appropriate combination of adaptation actions and responses.

A.3.2 Panel Assessment Process and Criteria

In the second stage, the Panel undertook an additional analysis of the 12 amalgamated risk areas. Panel members reviewed available evidence, including the outcomes of the workshop, and — through the use of another online survey — developed a final assessment of the potential consequences and likelihoods associated with the risks over a 20-year period. In this survey, Panel members responded to the following three questions:

Based on a scale of 0 to 100 where 0 = minimal impacts and 100 = catastrophic impacts, how would you assess the severity of the potential consequences of climate change for Canada in the following areas over the next 20 years?

Based on a scale of 0 to 100, where 0 = a 0% chance of occurrence and 100 = a 100% chance of occurrence, how would you assess the likelihood that climate change will result in significant damages, disruptions, or losses for Canada in the following areas over the next 20 years?

Based on your understanding of these risks, what percentage of the potential damages or losses in Canada from climate change do you think could be avoided in the following areas with an appropriate combination of adaptation actions and responses?

In answering the first question, Panel members were instructed to take into account both current adaptation plans and commitments and any expected autonomous adaptation. Panel members were also provided opportunities to elaborate on the rationale for their responses and to identify the criteria they considered and the impacts they identified in providing their assessment. The Panel then reviewed and discussed the survey results to ensure consensus. These results, which are broadly consistent with the outcomes from the workshop, formed the basis for the Panel's final identification of Canada's top climate risks viewed from a national perspective (Figure 2.3).

Throughout this process, the Panel relied primarily on the standard risk assessment criteria of consequences (i.e., the magnitude or scale of potential negative impacts) and likelihood. However, discussions of the consequences of climate change risks were informed by consideration of potential impacts across multiple domains. Based on discussions at the workshop, Panel deliberations, and reviews of criteria applied in other jurisdictions and contexts (e.g., Gov. of Japan, 2015; UN, 2015; Warren *et al.*, 2016), the Panel focused in particular on five general types of impact: (i) impacts on the environment and natural systems; (ii) impacts on the economy; (iii) impacts on society and culture; (iv) impacts on human health and wellness; and (v) impacts on geopolitical dynamics and governance.

While the Panel viewed Indigenous ways of life to be considerably at risk, given the lack of Indigenous members on the Panel and only limited inclusion of Indigenous knowledge in the assessment, it was less confident in its rating of the Indigenous ways of life risk area than for the other areas. The Panel also concluded that it could not produce a defensible evaluation of the adaptation potential of Indigenous ways of life. For this reason, the Indigenous ways of life risk area is not shown in Figures 3.1 or 3.3. Given the importance of this risk at the national level, however, it is still discussed in the text.

A.4 REPORT DRAFTING, REVIEW, AND PUBLICATION

Early drafts of this report were developed and revised based on collective feedback and discussion. As with all CCA reports, it was subject to a comprehensive review process; the Panel received formal peer-review comments from seven experts, comprising a wide range of expertise and professional backgrounds. Workshop participants were also given the opportunity to comment on a draft of the report. The final report was revised based on the Panel's full consideration of all peer-review feedback received.

A.5 STRATEGIES FOR IMPROVING FUTURE CLIMATE CHANGE RISK ASSESSMENTS

The Panel's process was tailored to the focus and needs of the Sponsor, and to the practical constraints associated with the project, which included a relatively accelerated timeframe (in comparison with most national climate change risk assessments) and limited resources for research and evidence-gathering. While the Panel believes this was the best available approach given the circumstances, and one that built on lessons learned in other jurisdictions, this approach has certain limitations.

Some of these limitations are common across all climate change risk assessments. Uncertainty stemming from multiple sources, including the complex interrelations between natural and social systems that characterize climate risks, is unavoidable given the current state of evidence. Additional research will improve understanding of some aspects of climate change and its impacts; however, other sources of uncertainty (including the path of future emissions and socio-economic conditions) will persist given their dependence on policy actions and geophysical responses that cannot be precisely predicted in advance. Uncertainty (and its relation to complex, systemic interactions) is recognized as a defining feature of climate change risk assessments, differentiating this type of risk assessment from those in more circumscribed contexts (Adger *et al.*, 2018; Brown, 2018; Brown *et al.*, 2018).

A reliance on expert judgment also has limitations, including any conclusion's vulnerability to distortion through collective decision-making (i.e., "group think"), individual cognitive biases, and incomplete information. However, as with uncertainty, these limitations cannot easily be avoided in climate change risk assessments, though they can be minimized with broad representation from experts across disciplines, regions, age groups, and organizational backgrounds. Objective evidence or standards pertaining to these risks are often lacking, and uncertainty about the evidence often calls for expert interpretation in order to assist decision-makers and governments seeking to understand and manage these risks. Expert judgment is central to climate change risk assessment (Adger *et al.*, 2018), and is likely to remain so for the foreseeable future.

Other methodological limitations, however, could be more effectively addressed in future national climate change risk assessments in Canada. Assessing such risks on a national scale is a significant undertaking. The time and resources available in this process did not permit the Panel to conduct an exhaustive review of all of the evidence, and the assessment may have missed recent research relevant to understanding these risks. Similar risk-assessment initiatives in other countries are often formally connected to a comprehensive evidence-gathering process, sometimes culminating in the production of an evidence report (as is the case in the United Kingdom). This has the advantage of tying the risk assessment to a comprehensive, dedicated review of the evidence, and helps ensure a common understanding of the risks (including their interrelations) among participating experts. In Canada's case, one approach to achieving this would be to formally tie future risk assessments directly to the comprehensive reviews of climate change impacts already undertaken (or currently underway) by the Government of Canada (Lemmen *et al.*, 2008; Warren & Lemmen, 2014b; NRCan, 2019a). Establishing such a connection would also help ensure that risk assessments are based on a timely synthesis of recent research, ideally conducted immediately following the completion of such an evidence report.

Future climate change risk assessments in Canada could also benefit from the involvement of a larger number of participating experts from multiple fields, sectors, and industries. While this process included the direct participation of 24 experts (as Panel members or workshop participants), and critical feedback from an additional 7 expert reviewers, the variety of climate change risks is so broad and the potential impacts across Canadian regions, sectors, and industries so varied, that some relevant perspectives and areas of expertise were not fully incorporated in the process. Individuals with expertise relating to all major Canadian industries and business sectors would help ensure a fuller appreciation of potential climate change impacts across the economy. Similarly, the regional dimensions of climate change are pronounced in Canada, highlighting the benefit of including those with in-depth knowledge on the risks and vulnerabilities for particular regions. Expanding the diversity of expertise at all stages (including evidence-gathering, risk assessment, and review) would further add to the rigour and credibility of future assessments.

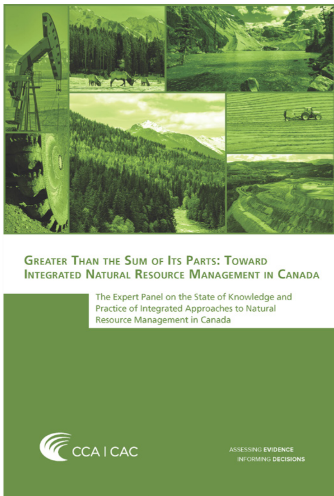
Some specific areas of risk also warrant assessments that take into account unique characteristics and contexts. Importantly, the Panel was limited in its ability to draw from Indigenous knowledge, which would require much broader involvement from Indigenous experts. Understanding the climate change risks facing Indigenous Peoples in Canada requires a deeper exploration of these risks in the spirit of reconciliation.

Future risk assessments would benefit from adequate time and resources for detailed, multi-criteria decision analysis. The capacity for this process to provide evaluations of climate impacts on specific criteria was constrained by the timeline and the evidence available. Future iterations, however, may benefit from adopting a structured approach to assessing individual criteria based on targeted assessments of the evidence. This would enable a formal multi-criteria analysis, and enhance transparency by illuminating the distribution of potential adverse impacts across individual criteria. However, any such efforts should take care to not imply a level of rigour or precision unwarranted by the state of the evidence or the assessment process. One reason the Panel refrained from a structured assessment of individual criteria was a lack of confidence in its ability to meaningfully evaluate impacts under these criteria based on the evidence available. The feasibility and credibility of a more structured and detailed risk assessment are therefore directly dependent on the resources and level of effort allotted to evidence-gathering.

Finally, public reactions to risk assessments are informative, and discussions of assessments with stakeholders and the public can enhance their effectiveness. These reactions constitute an additional layer of information on top of the scientific evidence (and therefore beyond the scope of this assessment) on the social acceptability and feasibility of risk management responses. Discussion sessions with specific groups or audiences (e.g., civil servants, professional organizations, local governments) complement broad, public engagement efforts, and could lead to additional insights. For these reasons, public and stakeholder discussions could be considered in future plans for federal climate risk assessments.

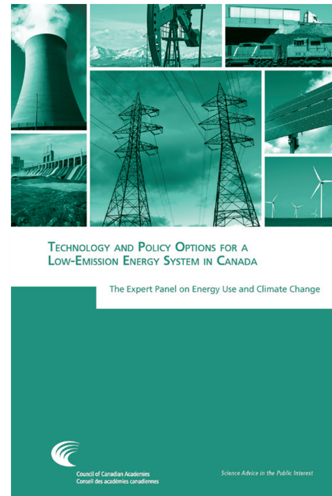
Council of Canadian Academies' Reports of Interest

The assessment reports listed below are accessible through the CCA's website (**www.cca-reports.ca**):

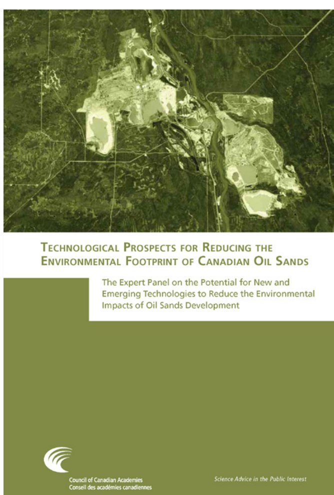


Greater Than the Sum of Its Parts: Toward Integrated Natural Resource Management in Canada
(2019)

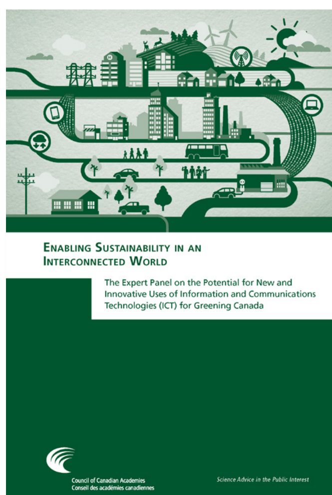
Commercial Marine Shipping Accidents: Understanding the Risks in Canada
(2016)



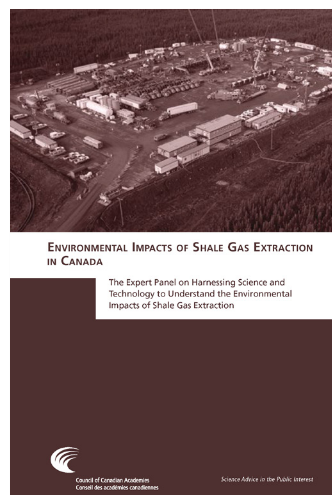
Technology and Policy Options for a Low-Emission Energy System in Canada
(2015)



Technological Prospects for Reducing the Environmental Footprint of Canadian Oil Sands
(2015)



Enabling Sustainability in an Interconnected World
(2014)



Environmental Impacts of Shale Gas Extraction in Canada
(2014)

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