Building a Resilient Canada

The Expert Panel on Disaster Resilience in a Changing Climate

CCA | CAC

Building a Resilient Canada

The Expert Panel on Disaster Resilience in a Changing Climate

CCA | CAC

The Council of Canadian Academies
180 Elgin Street, Suite 1401, Ottawa, ON, Canada, K2P 2K3

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 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 Public Safety (PS). Any opinions, findings, or conclusions expressed in this publication are those of the authors, the Expert Panel on Disaster Resilience in a Changing Climate, and do not necessarily represent the views of their organizations of affiliation or employment, or the sponsoring organization, PS.

Library and Archives Canada

ISBN: 978-1-990592-02-7 (book)
978-1-990592-03-4 (electronic book)

This report should be cited as:

Council of Canadian Academies, 2022. *Building a Resilient Canada*, Ottawa (ON). The Expert Panel on Disaster Resilience in a Changing Climate, Council of Canadian Academies.

Cover image

A fire break created in The Yukon, Courtesy of Government of Yukon.

Disclaimer

The internet data and information referenced in this report were correct, to the best of the CCA's knowledge, at the time of publication. Due to the dynamic nature of the internet, resources that are free and publicly available may subsequently require a fee or restrict access, and the location of items may change as menus and webpages are reorganized.

CCA | CAC

Printed in Ottawa, Canada

Canada

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

The Expert Panel on Disaster Resilience in a Changing Climate would like to acknowledge the Inuit, Métis, and First Nations Peoples who have been stewards of the lands now known as Canada. For generations, Indigenous Peoples have collected knowledge and developed practices to promote community resilience in a changing environment.

The Council of Canadian Academies (CCA) acknowledges that our Ottawa offices are located in the unceded, unsurrendered ancestral home of the Anishinaabe Algonquin Nation, which has historically nurtured the land, water, and air of this territory and continues to do so today. Though our offices are in one place, our work to support evidence-informed decision-making has broad potential benefits and can hopefully contribute to collective action to address long-standing inequities and injustices impacting Indigenous Peoples. We are committed to drawing on a range of knowledges and experiences to inform policies that will build a stronger, more equitable, and more just society.

The Council of Canadian Academies

The Council of Canadian Academies (CCA) is a not-for-profit organization that supports independent, science-based, authoritative expert assessments to inform public policy development in Canada. Led by a Board of Directors and advised by a Scientific Advisory Committee, the CCA's work encompasses a broad definition of science, incorporating the natural, social, and health sciences as well as engineering and the humanities. CCA assessments are conducted by independent, multidisciplinary panels of experts from across Canada and abroad. Assessments strive to identify emerging issues, gaps in knowledge, Canadian strengths, and international trends and practices. Upon completion, assessments provide government decision-makers, researchers, and stakeholders with high-quality information required to develop informed and innovative public policy.

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, and any level of government.

www.cca-reports.ca

@cca_reports

The Academies

The CCA is 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.

The Canadian Academy of Engineering (CAE)

The CAE is the national institution through which Canada's most distinguished and experienced engineers provide strategic advice on matters of critical importance to Canada. The Academy is an independent, self-governing, and non-profit organization established in 1987. Fellows are nominated and elected by their peers in recognition of their distinguished achievements and career-long service to the engineering profession. Fellows of the Academy are committed to ensuring that Canada's engineering expertise is applied to the benefit of all Canadians.

The Canadian Academy of Health Sciences (CAHS)

The CAHS recognizes excellence in the health sciences by appointing Fellows based on their outstanding achievements in the academic health sciences in Canada and on their willingness to serve the Canadian public. The Academy provides timely, informed, and unbiased assessments of issues affecting the health of Canadians and recommends strategic, actionable solutions. Founded in 2004, CAHS appoints new Fellows on an annual basis. The organization is managed by a voluntary Board of Directors and a Board Executive.

The Expert Panel on Disaster Resilience in a Changing Climate

Under the guidance of its Scientific Advisory Committee, Board of Directors, and founding Academies, the CCA assembled the Expert Panel on Disaster Resilience in a Changing Climate to undertake this project. Each expert was selected for their expertise, experience, and demonstrated leadership in fields relevant to this project.

Scott Vaughan (Chair), Senior Fellow, International Institute for Sustainable Development (IISD); former Federal Commissioner of the Environment and Sustainable Development (Ottawa, ON)

Alain Bourque, Executive Director, Ouranos (Montréal, QC)

Elliott Cappell, former Director, Climate Change, WSP Canada (Toronto, ON)

Stephanie E. Chang, Professor, School of Community and Regional Planning (SCARP) and Institute for Resources, Environment and Sustainability (IRES), University of British Columbia (Vancouver, BC)

Jimena Eyzaguirre, International Team Director and Senior Climate Change Adaptation Specialist, ESSA Technologies Ltd. (Ottawa, ON)

Mike Flannigan, BC Innovation Research Chair in Predictive Services, Emergency Management and Fire Science, Faculty of Science, Thompson Rivers University (Kamloops, BC)

Kathryn Hyland, former Senior Vice-President, Risk Management, Swiss Re (Toronto, ON)

Tara McGee, Associate Dean (Engagement and EDI), Faculty of Science and Professor, Department of Earth and Atmospheric Sciences, University of Alberta (Edmonton, AB)

Kevin Quigley, Professor, School of Public Administration and Scholarly Director, MacEachen Institute for Public Policy and Governance, Dalhousie University (Halifax, NS)

Roger Rempel, Climate Change Technical Service Lead, Dillon Consulting (Winnipeg, MB)

Sarah Sargent, VP, Risk Reduction Programs, Canadian Red Cross (Ottawa, ON)

Message from the President and CEO

Like many parts of the world, Canada is witnessing the impacts of recent floods, wildfires, and heat waves offering a dramatic reminder of just how wide-ranging and damaging extreme weather can be. As the frequency and severity of these hazards increase, the resilience of individuals, communities, and infrastructure will similarly be tested. Current risk management approaches, often designed for single events, may be insufficient to prepare for future disasters arising from these and other events, particularly where such hazards are overlapping.

While often referred to as natural disasters, this term is increasingly falling out of favour. Hazards can become disasters when people and property end up in harm's way without the proper reinforcements and protection. Reducing disaster risks will require a multifaceted approach that improves the resiliency of both people and systems. Integrated responses are more efficient and effective and help to stretch limited resources further. This was the context for Public Safety Canada asking the CCA to examine opportunities to better integrate climate change adaptation and disaster risk reduction efforts to enhance resilience. Panel members brought expertise in sustainable development, insurance, planning, policy, and resilience.

Building a Resilient Canada identifies essential actions to reduce vulnerability and exposure to natural hazards through the integration of climate change adaptation and disaster risk reduction. The report includes examples relevant for governments, businesses, individuals, and other stakeholders. This adds to the growing collection of CCA reports focused on climate and the environment, including those which have evaluated the evidence to promote integrated approaches to natural resource management and examined Canada's top climate change risks.

The Panel, chaired by Scott Vaughan, had the additional challenge of undertaking this work entirely virtually and I thank each member for their time and dedication on this project. Thanks also to the CCA's Board of Directors and Scientific Advisory Committee, and its founding Academies — the Royal Society of Canada, the Canadian Academy of Engineering, and the Canadian Academy of Health Sciences — for their guidance and oversight throughout the assessment process.

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

Message from the Chair

Extreme weather is affecting thousands of Canadian families, pressing the capacities of first responders, increasing insured and wider economic costs of disasters, and dominating media headlines. Never have the impacts of extreme weather events been starker than during the summer and fall of 2021. More than a dozen Canadian temperature records were smashed, with Squamish, B.C. recording over 40°C. The B.C. coroner's office recorded a 300% spike in sudden, unexpected deaths during the week of June 25th, 2021, which was attributed to the heat waves that covered western Canada and the United States for days. Extreme heat helped fuel thousands of wildfires throughout the summer, including the destruction of the town of Lytton, B.C., and extensive damages to the town of Monte Lake, B.C. In November 2021, the same region was hit by unprecedented flooding. Record-breaking rainfall triggered landslides in areas where vegetation had been lost during the summer, illustrating the tragic, dangerous, and costly impacts of cascading hazards.

In addition to the economic costs of these events, the psychological and well-being effects on displaced and at-risk individuals and households are likely to be long-lasting. Farmers from lower British Columbia and across the Prairies to Northwestern Ontario faced extreme and exceptional drought conditions throughout 2021, affecting water, crops, and livestock health. Fifty years ago, song-writer Paul Simon wrote "I get the news I need on the weather report." In 2021 it turned out to be true.

Past practices have treated many of these weather events as anomalies — exceptional events that happen once every 100 years. However, as Canadian average temperatures have already risen by 1.7°C — far higher than the global average — more extreme weather events are becoming a new and more hostile normal. The 2021 release of the Sixth Assessment Report of the Intergovernmental Panel on Climate Change notes that many climate impacts are now irreversible.

Our report identifies ways to strengthen the capacity of Canadian households, communities, economic sectors, and institutions to anticipate, prepare for, mitigate, and prevent the damages of extreme weather events. A main focus of the Panel's work is identifying ways to integrate disaster risk reduction efforts with climate adaptation. The Panel welcomed its charge to identify successful pathways to bridge the disaster risk reduction and climate change adaptation communities within the context of bolstering wider public safety for all Canadians.

Among the opportunities identified in this report is ensuring that timely, comprehensive, accessible, and robust data on extreme weather events are available at a pan-Canadian level. Extreme event data can backstop disaster risk response and climate adaptation planning and deployment in the same way Statistics Canada data backstops economic management and planning. The Panel highlights the important role that experts play in bridging and brokering data to make it useful at the community, county, household, and business level. A second key focus of the Panel report is advancing the work of both public and private finance, insurance, and reinsurance to better prepare Canadians for more extreme weather events. Examples include lowering insurance premiums for households with backwater flood valves, supporting better building codes and engineering practices to climate-proof buildings, and dissuading homeowners from building or rebuilding on floodplains.

A third focus of the report is the need to support decision-making at the right level: while national plans and federal and provincial budgets advance climate resilience, local communities are best placed to anticipate, reduce, and even prevent risks and hazards from becoming natural disasters. Nowhere is this more pressing than in supporting Indigenous communities in disaster preparedness and resilience, including by engaging with Indigenous and Local Knowledge.

Given the challenges ahead, I hope our report will contribute to managing the known and emerging risks ahead, by more closely aligning disaster risk response and climate change adaptation communities. I want to express my thanks to Public Safety Canada for this important charge. I also want to extend my sincere gratitude to the outstanding members of the CCA secretariat through this process. And finally, my deep thanks to every member of the Panel for their extraordinary expertise and commitment to working, listening, and learning together.

Scott Vaughan
Chair, The Expert Panel on Disaster Resilience in a Changing Climate

CCA Project Staff

Assessment Team:	**Jérôme Marty,** Project Director
	Suzanne Loney, Senior Research Associate
	Dane Berry, Research Associate
	Vasa Lukich, Research Associate
	Meagan Siemaszkiewicz, Researcher
	Weronika Zych, Senior Project Coordinator
	Tijs Creutzberg, Director of Assessments

With assistance from:

Design	gordongroup
Editor	Lisa Muirhead / Firefly Communications
Translator, En-Fr	François Abraham, traducteur agréé, Communications Léon inc.

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:

Maureen J. Chapman, Chief and Senior Advisor, Stó:lo and Skawahlook First Nation (Agassiz, BC)

Robin S. Cox, Professor, Director, ResilienceByDesign Lab, Royal Roads University (Victoria, BC)

Mark Crosweller, Founder and Director, Ethical Intelligence (New South Wales, Australia)

Blair Feltmate, Head, Intact Centre on Climate Adaptation, University of Waterloo (Waterloo, ON)

Robert Glasser, Head, Australian Centre for Climate and Security, Australian Strategic Policy Institute (Canberra, Australia)

Ilan Kelman, Professor of Disasters and Health, University College London (London, United Kingdom); Professor II, University of Agder (Kristiansand, Norway)

Anne Kendrick, Independent Consultant; former Senior Policy Advisor, Inuit Tapiriit Kanatami (Ottawa, ON)

Ian Mauro, Executive Director, Prairie Climate Centre and Associate Professor, Department of Geography, University of Winnipeg (Winnipeg, MB)

Tamsin Mills, Resilience Consulting; Senior Sustainability Specialist, City of Vancouver (Vancouver, BC)

Alyson Slater, Senior Director, Sustainable Finance, Global Risk Institute in Financial Services (Toronto, ON)

Francis Zwiers, Director, Pacific Climate Impacts Consortium, University of Victoria (Victoria, BC)

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 Full 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 report review requirements have been satisfied. The CCA thanks Dr. Dawson for her diligent contribution as peer review monitor.

Acknowledgements

The Panel and CCA staff would like to express their sincere appreciation to the following people who provided information and perspectives for consideration by the Panel:

Amy Cardinal Christianson, Fire Social Scientist, Canadian Forest Service, Natural Resources Canada (Edmonton, AB)

Tom De Groeve, Deputy Head of the Disaster Risk Management Unit, European Commission Joint Research Centre (Ispra, Italy)

David Diabo, Special Advisor – Emergency Services, Assembly of First Nations (Ottawa, ON)

Anne Hammill, Senior Director, Resilience, International Institute for Sustainable Development (Toronto, ON)

David Murchison, Vice President, International, Institute on Governance (Ottawa, ON)

Brenda Murphy, Former Co-Chair, Indigenous Resilience Working Group, Canadian Platform for Disaster Risk Reduction and Professor and Chair, Social and Environmental Justice (Undergraduate) and Social Justice and Community Engagement (Graduate), Wilfrid Laurier University (Brantford, ON)

Erin Myers, Environment and Climate Change Advisor, Métis National Council (Ottawa, ON)

Madeleine Redfern, President, Ajungi Arctic Consulting (Iqaluit, NU)

Executive Summary

Every year brings new evidence that people in Canada are increasingly exposed to hazards in a changing climate. In 2020, while the global pandemic dominated headlines, weather-related disasters resulted in $2.4 billion in insured damages in Canada. In 2021, Western Canada suffered an unprecedented heat wave, contributing to hundreds of deaths and numerous wildfires. With the frequency and severity of extreme weather increasing, insured losses from such events regularly measure billions of dollars per year. These figures significantly understate the impacts of such events given (i) that a large share of disaster losses are uninsured, and (ii) the potential of extreme weather events to cause loss of life, the destruction of natural habitats, and other harm. The likelihood of multiple concurrent disasters is also rising as climate change intensifies, as is the prospect of cascading events and nonlinearities wherein small increases in the severity of a hazard yield outsized differences in consequences. Many existing systems for managing risk are not evolving rapidly enough to keep pace with the changing environment, leading to a growing sense of crisis. As of November 2021, just over 2,000 jurisdictions in 37 countries had declared "climate emergencies," including the House of Commons and 517 local governments in Canada. These declarations reflect the recognition that communities are increasingly at risk and current action is insufficient given the challenges posed by a changing climate.

As climate-related hazards increasingly depart from historical norms, minimizing exposure and vulnerability to these threats requires taking full advantage of the complete spectrum of knowledge and resources available — regardless of the discipline or department where they originate. Disciplinary and bureaucratic silos often lead to inefficient use of resources and a lack of coordination and alignment. Climate change adaptation (hereafter adaptation) and disaster risk reduction (DRR) developed separately and mostly in parallel as areas of research, policy, and practice. Differences in terminology, institutions, culture, values, and interests all combine to limit the effective integration of these two domains, frequently impeding progress on enhancing resilience.

Recognizing this challenge in the context of the disruptions and damages brought about by disasters and the hazards of a changing climate, Public Safety Canada (PS) asked the Council of Canadian Academies (CCA) to convene an Expert Panel to answer the following question:

What key opportunities exist to improve disaster resilience in Canada through better integration of disaster risk reduction and climate change adaptation research and practice?

In response to this request, the CCA assembled an interdisciplinary panel of experts in adaptation and DRR, which met virtually over the course of 2020 and 2021 to evaluate evidence and deliberate on its charge.

Report Findings

Governments, businesses, communities, and households are adapting to a changing climate. The Panel explored a wide range of evidence and examples of governments and other actors seeking to improve resiliency to climate-related hazards by better integrating adaptation and DRR. Whether it is cities mandating green roofs to reduce the effects of heat waves and urban flooding, investors calling for enhanced climate risk disclosures, or public disaster relief programs encouraging rebuilding in ways that will better withstand future hazards, there are many ways that adaptation and DRR can be more effectively integrated to reduce risks. Canadian governments and communities can learn from initiatives abroad, though differences in context may make it necessary to tailor policies, practices, or programs to local circumstances. Reflecting on the complete range of evidence reviewed and expert perspectives brought by Panel members, the main insights that emerged from this Panel's work are summarized in the following findings.

Finding 1: An ongoing failure to fully integrate climate change adaptation into DRR activities, policies, and tools reduces the efficiency and impact of public investments in disaster resilience, leaving Canadian communities at risk.

The resources available to enhance disaster resilience in any society are limited; maximizing their benefits requires investing them in ways that take advantage of synergies and cross-fertilization while avoiding duplication. But existing structures and approaches to DRR often fail to deploy these resources optimally. At the most basic level, most governments persistently underinvest in mitigation and later pay the price in terms of disaster response and recovery. Existing analyses suggest that the costs of preparedness and mitigation are several times lower than the savings these measures create. For example, flood mitigation spending is a particularly sound investment: one Canadian analysis reported that every $1 spent on reducing residential basement flood risks led to $11 in savings and found that the implementation of the tools and guidelines, established by Canada's Climate-Resilient Buildings and Core Public Infrastructure initiative, could yield annual benefits of $4.7 billion. A U.S. study estimated an average benefit–cost ratio for adopting up-to-date model building codes of 6:1 for riverine flood hazards and 10:1 for wind hazards. There is abundant, well-documented evidence that carefully designed, proactive investments in disaster resilience save money in the long term. The level of demand for financial support for disaster response and recovery in Canada through the federal Disaster Financial Assistance Arrangements program further underscores the need to prioritize investments that reduce the impacts of disasters before they happen.

In a changing climate, historical norms previously used to inform such investments are no longer a reliable guide. This is well-recognized in theory, but all too often, limited efforts have been made to adjust decision-making accordingly. Codes, standards, and flood maps that are designed in part based on historical climate data are key examples of this disconnect. Risk assessments also benefit from an integrated approach. Comprehensive, all-hazard analyses that establish and consider the full risk landscape — including climate-related and other hazards together — clarify where resources are most needed, help identify solutions that address multiple risks, and improve the understanding of relationships between risks. The lack of a publicly available, integrated, all-hazard risk assessment in Canada makes it difficult to compare risks and be strategic about deploying resources where they could have the greatest possible benefit. Employing risk assessments to inform land-use planning offers an opportunity to reduce or avoid risk or retreat from some hazards altogether. Where hazards cannot be avoided, the development and enforcement of codes and standards that integrate climate change data can better prepare physical structures to withstand the effects of hazards. Not taking such steps leaves communities and individuals preparing for the disasters of the past rather than those of the future.

Finding 2: Successfully integrating adaptation and DRR requires overcoming barriers such as disciplinary and departmental silos, conceptual and terminological differences, and jurisdictional misalignments while accounting for perceptions and cognitive biases that affect decision-making.

Efforts to spur greater integration between adaptation and DRR are unlikely to succeed unless they anticipate common barriers to progress. Some barriers stem from these domains operating at different scopes and scales, often in separate government departments and using diverse terminology. Within DRR, a continuing focus on responding to emergencies has not provided adequate avenues for more holistic preparedness, prevention, and mitigation activities, let alone the inclusion of adaptation. Mutual knowledge sharing and collaboration can support integration, as can inter-agency coordination and the adjustment of institutional mandates, in instances when separate agencies focus on adaptation and disaster preparedness and response.

Misalignments in the responsibilities and resources of different orders of governments (or departments and agencies within governments) also impede progress. Indigenous and municipal governments are often best placed to manage mounting disaster risks due to their better awareness of local conditions and community capacity, but they lack the resources or authority to take effective action. Municipalities' authority is vested in them by provinces, and many risk-reduction measures or investments must be approved by provincial governments. Municipalities also depend on property taxes for income, often placing their income stream at odds with land-use measures that could reduce the exposure of populations or infrastructure to known hazards. Further challenges exist for small municipalities and remote communities where resources are scarce and essential services are already overburdened or nonexistent. Effective integration between adaptation and DRR frequently requires the development of collaborative structures and platforms. Such collaborative undertakings can overcome misalignments through the explicit recognition of roles and responsibilities and provide the basis for an effective sharing of resources and knowledge.

Other barriers to improving resilience are shared by both domains. Individuals will decide if and how to take protective action based on how they process the risk information they receive, their threat assessment, and their judgment as to whether one or more responses are likely to be feasible and effective. Risk perception is shaped by many factors, including past experience and social context. In addition, common cognitive biases contribute to near-term thinking, inertia, and optimism about individual risks. These biases confound efforts to build disaster resilience in the same ways that they forestall efforts to proactively adapt to a changing climate. Research on the factors described above offers lessons on how programs — and particularly communications materials — can be better designed to motivate resilience investments in the face of these obstacles.

Finding 3: The integration of adaptation and DRR requires a combination of i) information systems adapted to the needs of decision-makers and ii) flexible funding, financing, and insurance arrangements that support proactive investment.

Improving the knowledge base is often the first step in integrating adaptation into DRR. The Panel identified several areas where a lack of information is a challenge in Canada, including the quality and availability of extreme weather records (particularly in remote locations), disaster data, and economic analyses of the costs and benefits of adaptation. Timely, comparable, and comprehensive disaster data is essential to monitoring and evaluating risk over time; the Canadian Disaster Database is currently not meeting this need. More research on nature-based solutions is also needed. Interest in these types of interventions and their potential to reduce climate-related risks is growing, but a lack of evidence on their effectiveness when deployed across larger geographical scales (and over longer time periods) makes it difficult to assess their potential. Additionally, better documentation of best practices and engineering guidelines for nature-based solutions could facilitate the wider deployment of these strategies. Economic data that provides insights on the relative costs and savings of disaster resilience investments could help identify priority areas and clarify the business case. Finally, the continuing underreliance on Indigenous and Local Knowledge and the underutilization of disaster-related expertise developed by Indigenous organizations and in Indigenous communities undermine disaster resilience in Canada.

Despite these challenges, many promising approaches were identified by the Panel. By focusing investments on the expansion of high-resolution climate data and information about extreme weather events, decision-makers will be better equipped to establish effective DRR strategies at the local level. Applying Indigenous and Local Knowledge to integrate DRR and adaptation can improve the understanding of risks and actions, which may enhance resilience while simultaneously providing a range of co-benefits, including community empowerment and sustainable resource management. All-hazards risk assessments that incorporate climate projections offer decision-makers and practitioners one of the most useful means of integration. Ensuring that information collected by all-hazards risk assessments is fully accessible to the public (i.e., both available and readily understandable without specialized knowledge or expertise) helps to further enhance its utility and value. Lastly, effective risk communication addresses the needs of communities in a timely and comprehensive manner, and knowledge brokers are a key means of communication. Acting as an intermediary between researchers and information users, knowledge brokers enable two-way dialogue and aid effective decision-making even in the face of uncertainty.

Insurance policies, public funding, and private investment decisions also play roles in supporting action. These arrangements can take many forms. Home insurance policies can create awareness about disaster risks, reward (or even require) risk mitigation activities, and provide financial stability in the event of harm. Public–private partnerships provide one means of increasing insurance coverage when risks are high and affordability is a concern; these partnerships may have an important role to play in a changing climate with the increasing concentration of people and assets in hazard-exposed areas. Public disaster relief programs can be adjusted to encourage decision-makers to take further protective measures and to rebuild differently — and perhaps elsewhere — when disasters do arise. Enhanced corporate disclosure of the physical risks of climate change improves investor awareness, driving capital allocation and encouraging risk mitigation. Public investments in infrastructure also offer opportunities for enhanced resilience, especially when a climate lens is used to evaluate projects, thereby increasing their value and longevity.

Finding 4: Whole-of-society collaboration as well as government mandates are necessary to operationalize integration.

The complexity of disaster risks — in terms of the breadth of hazards, the geographic range and jurisdictional scales implicated, the interconnectivity of current systems and potential for cascading impacts, and the multitude of factors influencing exposure and vulnerability — warrants a complex response. There is no one authority with the knowledge, capacity, and power to act on all fronts. Instead, comprehensive strategies to build disaster resilience require the involvement of government, civil society, the private sector, and individual households. Leveraging the knowledge and capacities of local communities is critical for ensuring that DRR and adaptation activities and policies work to improve resilience and promote decision buy-in. Policies, regulations, codes, and standards all drive local progress, but mandates must go hand in hand with adequate financial resources and locally relevant information. Central governments can provide essential funding and information while playing a vital coordinating role to ensure the clear delineation of responsibility among actors and complementary regional direction. Increased decision-making transparency through whole-of-society collaboration or public audits in the wake of disasters can drive greater public involvement and accountability. Values underpin all these interventions; the risks that a society recognizes are a product of values, and values subsequently inform the choices a society makes about managing these risks.

Effective DRR and adaptation both hinge on information that is available, accessible, and applicable to a range of decision-making contexts, alongside funding, investment, and insurance programs and policies that motivate appropriate actions.

Appropriate governance structures are then called for to integrate DRR and adaptation, including whole-of-society, bottom-up processes alongside top-down government mandates. All these elements come together to bring about actions at individual, neighbourhood, city, and regional scales to lessen hazards, vulnerability, and exposure in a changing climate (Figure 1). There are limited means to temper hazards, including urban greening to lower temperatures and fuel management for fire prevention. A wider range of strategies is available to reduce exposure, including land-use planning to prevent development in exposed areas, planned retreat, and protective infrastructure. Physical vulnerability can be lowered through codes and standards and community and home maintenance measures, while social vulnerability can be lowered through community assets such as cooling centres and by building redundancies into infrastructure systems and supply chains.

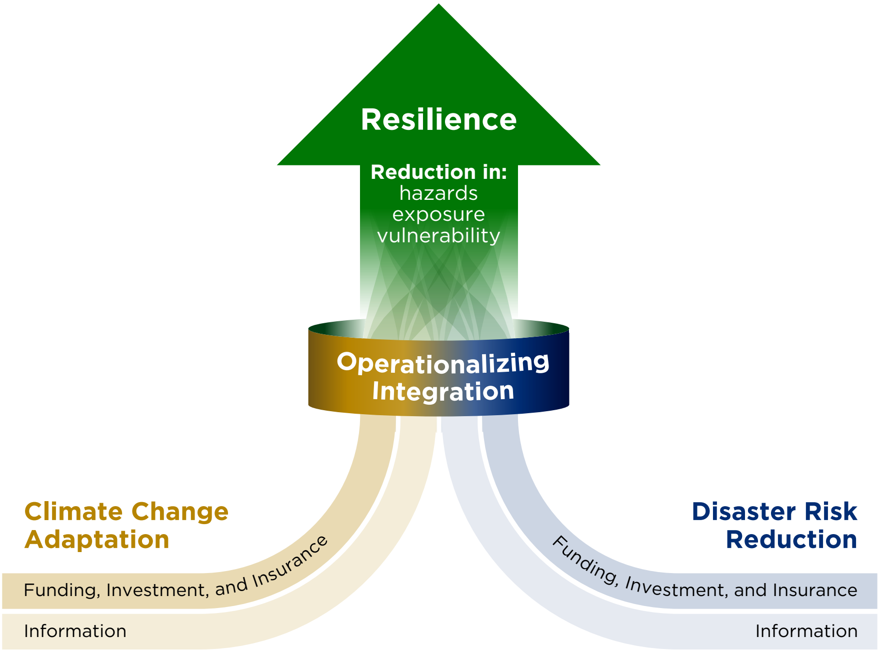


Figure 1 Conceptual Framework for Improving Disaster Resilience through the Integration of DRR and Adaptation

There is an opportunity to enhance disaster resilience through the integration of DRR and adaptation. In particular, information resources, funding programs, investment choices, and insurance offerings that factor in climate change alongside other DRR considerations will contribute to more effective decision-making. Integration requires systems to operationalize these tools and interventions through whole-of-society engagement, local leadership, and well-enforced legislation.

Towards a More Resilient Future

Climate-related disasters are neither natural nor inevitable. Disasters result from interactions between communities and naturally occurring hazards and are the consequences of human choices at both individual and societal scales. Recognizing this element of choice is essential to creating accountability and motivating action to manage disaster risks in a changing climate, but it is also essential to recognize that many actors — especially vulnerable groups — face various constraints that limit their choices. The integration of adaptation and DRR is only one aspect of improving resilience. Another part of enhancing disaster resilience is addressing root causes of vulnerability in society, which involves addressing other social needs, such as supporting vulnerable populations, reducing income inequality, and alleviating poverty. Similarly, further progress on reconciliation and Indigenous self-governance will advance resilience by enhancing self-determination and improving government-to-government relations. Finally, the resilience of communities is linked to the resilience of the ecosystems they depend on; a comprehensive approach to assessing and cultivating resilience includes greater efforts to understand and enhance the resilience of natural systems to the hazards posed by climate change. In all these areas, as with mitigating climate change in general, the choices we make today will determine the extent to which our communities remain vulnerable and exposed to climate-related hazards in the decades to come.

Abbreviations

AHRA	All-Hazards Risk Assessment
Cat models	catastrophe models
CDD	Canadian Disaster Database
DRR	disaster risk reduction
ECCC	Environment and Climate Change Canada
EMAP	Emergency Management Assistance Program
FPT	federal, provincial, and territorial
GDP	gross domestic product
GHG	greenhouse gas
IDF	intensity-duration-frequency
ILK	Indigenous and Local Knowledge
IPCC	Intergovernmental Panel on Climate Change
NBS	nature-based solution
NGO	non-governmental organization
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PS	Public Safety Canada
TCFD	Task Force on Climate-Related Financial Disclosures

Contents

1 Introduction 1

1.1 The Charge to the Panel. 4

1.2 The Panel's Approach 5

1.3 Impacts and Implications of COVID-19 12

1.4 The Structure of the Report 13

2 Context and Motivation 14

2.1 Disaster Risk Reduction 15

2.2 Climate Change Adaptation. .24

2.3 Integrating Disaster Risk Reduction and Climate Change Adaptation 28

2.4 Conclusion 35

3 Key Interventions for Building Disaster Resilience in a Changing Climate 36

3.1 Reducing Hazards 38

3.2 Reducing Exposure to Hazards. 41

3.3 Reducing Vulnerability to Hazards. 49

3.4 Conclusion 56

4 Information for Disaster Resilience Decision-Making . . . 58

4.1 Existing Barriers and Incentives 60

4.2 Promising Approaches 67

4.3 Capabilities 79

4.4 Key Opportunities for Integration 81

5 Insuring, Funding, and Investing in Disaster Resilience . . 82

5.1 Existing Barriers and Incentives 84

5.2 Promising Approaches 90

5.3 Capabilities 100

5.4 Key Opportunities for Integration 101

6 Operationalizing Integration of DRR and Adaptation . . 102

6.1 Building Effective Coalitions for Enhancing Disaster Resilience 104

6.2 Compelling Action to Improve Disaster Resilience. 118

6.3 Key Opportunities for Operationalizing Integration 123

7 Towards a More Resilient Future 124

7.1 Choosing Resilience 125

7.2 Panel Reflections 125

References 128

1

Introduction

1.1 The Charge to the Panel
1.2 The Panel's Approach
1.3 Impacts and Implications of COVID-19
1.4 The Structure of the Report

A mid-size Canadian city is hit with a major flood event. An old system of dikes and berms rated for a 1-in-50-year flood fails. A state of emergency is declared: lives are lost, injuries are sustained, and many homes and businesses are damaged. Some of the damaged buildings were knowingly constructed on the floodplain, with local governments having allowed extensive construction to address growing population pressures as well as to access property taxes needed to fund other municipal projects. The flooding of other buildings came as a complete surprise, owing to out-of-date flood maps that did not account for climate change. In the aftermath, many property owners discover that their insurance does not cover flood damages. Those who do have insurance must rebuild using the same building codes and standards as were used in the initial build. Low-income citizens bear the greatest burden of this disaster due to their lack of insurance coverage and limited savings, and they must rely on public disaster relief to rebuild as best they can. All residents deal with disruptions to daily life. Some file employment insurance claims as various businesses are temporarily closed, and the stress takes a major toll on many households. As the community rebuilds, the stage is once again set for the next disaster.

In an alternative future, this same city experiences the same flood event but faces a very different set of consequences. There are few damaged buildings and no serious casualties. The majority of the floodplain is uninhabited, barring a few historic properties, as a result of a government-funded property buy-back initiative. Relatively low-cost investments in natural flood defences on public lands translate to major savings as wetlands absorb much of the flood water. The homes and businesses that did experience flooding were aware of their risks owing to up-to-date flood maps and proactive community engagement on flood hazards, and property owners had been incentivized to invest in low-cost, high-impact measures to mitigate flood risks. The damages that did occur were covered by insurance claims, and policies encouraged thoughtful rebuilding that would enhance resilience in the event of future floods. Ultimately, the same weather event unfolded, but no disaster ensued.

This simplified narrative does not reflect the full complexity and scope of disaster resilience; for instance, how the most damaging effects of a disaster in an Indigenous community may result from the mental health effects of evacuations that fail to address community needs and values (HoC, 2018). Nonetheless, the individual elements highlighted here demonstrate the precarious position Canada finds itself in. Land-use decisions, population growth, and rapid economic development have greatly increased the exposure of populations, driving up the cost of losses over the last few decades. Climate change is altering the frequency, severity, and distribution of natural hazards, further exacerbating risk.

In 2020, natural disasters resulted in $2.4 billion of insured damages in Canada, with the Calgary hailstorms alone accounting for $1.3 billion of that value (IBC, 2021). *The Global Risks Report 2021* by the World Economic Forum found extreme weather and climate action failure to be among the top risks faced by societies worldwide (WEF, 2021). Impacts resulting from climate change are being felt now and are only projected to become more frequent and intense in the future, emphasizing the need for immediate action to reduce future disaster risk (Zhang *et al*., 2019). Even with strong global actions to reduce greenhouse gas (GHG) emissions, warming experienced to date, and future warming that will occur before anthropogenic emissions reach net zero, will be here to stay (Flato *et al*., 2019). The Intergovernmental Panel on Climate Change (IPCC) observes that "many changes due to past and future GHG emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level" (IPCC, 2021). According to the Global Commission on Adaptation (GCA, 2019), "choosing between adaptation and [climate change] mitigation is a false choice — we must do both."

Reflecting the urgent need to deal with mounting climate hazard risks, the House of Commons declared a national climate emergency in 2019 to urge Canada to meet its emission reduction targets and spur further GHG reductions (HoC, 2019; Jackson, 2019). This declaration is part of a global trend; as of November 2021, just over 2,000 jurisdictions in 37 countries had declared "climate emergencies," including 517 local governments in Canada (CED, 2021). In the context of the COVID-19 pandemic, many are citing climate change as an even greater threat that requires immediate attention on the global scale (Chapagain & Steer, 2020; Fuentes *et al*., 2020; IMF, 2021).

This report identifies a series of current practices and emerging actions to reduce vulnerability and exposure to natural hazards through the integration of climate change adaptation (hereafter referred to as adaptation) and disaster risk reduction (DRR). These actions are diverse, encompassing both structural (e.g., levees, sea walls) and non-structural (e.g., planned retreat, insurance) interventions; however, they rest on a common foundation of accessible and up-to-date information, sufficient funding and insurance incentives, and coordinated and collaborative governance. This echoes the call by the Global Commission on Adaptation for revolutions in understanding climate risks, financing required actions, and planning for the future (GCA, 2019). Enhancing the resilience of individuals, communities, and the built environment is a crucial process that requires a multifaceted approach.

1.1 The Charge to the Panel

Recognizing the increasing frequency and severity of many hazards in a changing climate and the extent of disruptions and damages brought about by recent Canadian disasters, Public Safety Canada (PS; the Sponsor) asked the Council of Canadian Academies (CCA) to convene an Expert Panel to answer the following question and sub-questions:

What key opportunities exist to improve disaster resilience in Canada through better integration of disaster risk reduction and climate change adaptation research and practice?

- What institutional barriers, incentives, and disincentives prevent the effective integration of climate change adaptation and disaster risk management in Canada?
- What climate-related tools, data sources, methods, and frameworks are underutilized in Canada's existing disaster risk reduction efforts? What disaster risk reduction tools, data sources, methods, and frameworks are underutilized in climate adaptation initiatives and practice?
- What adaptation and disaster risk reduction capabilities are required to enhance resilience to climate-related natural disasters in the future?

The CCA assembled an interdisciplinary panel of experts with knowledge about adaptation and DRR and a diverse range of backgrounds, including sustainable development, insurance, planning, policy, and resilience. The Expert Panel on Disaster Resilience in a Changing Climate (the Panel) was asked to identify current barriers to the integration of adaptation and DRR, as well as promising approaches for enhancing resilience to disasters through increased integration. The Panel met virtually over the course of 2020 and 2021 to evaluate evidence and deliberate on the charge.

1.2 The Panel's Approach

1.2.1 Terminology

The fields of DRR and adaptation often define key terms and interpret the same concepts in different ways (Birkmann *et al.*, 2009). In light of this, the Panel emphasized the importance of having clear, agreed-upon definitions and an understanding of terminology to prevent confusion and enable effective communication across a broad spectrum of audiences. Box 1.1 provides the adopted definitions for key terms applied in this report.

Box 1.1 Definitions of Key Terms

Adaptation: "The process of adjustment to actual or expected climate and its effects. [In human systems, adaptation seeks] to moderate harm or exploit beneficial opportunities [...] In natural systems [...] human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2018).

Disaster: "A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts" (UNDRR, 2016).

Disaster Risk Reduction: "The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through the mitigation and prevention of exposure to hazards, decreasing vulnerability of individuals and society, strategic management of land and the environment, improved preparedness for disaster risks, coordinated response and planning, and forward looking recovery measures" (MREM, 2017).

Emergency (Disaster) Management: "The organization, planning and application of measures preparing for, responding to and recovering from disasters" (UNDRR, 2016).

Exposure: "The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas" (UNDRR, 2016).

Hazard: "A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" (UNDRR, 2016).

(Continues)

(Continued)

Mitigation: The Panel adopted the DRR community's usage, defining mitigation as "the lessening or minimizing of the adverse impacts of a hazardous event" (UNDRR, 2016). It should be noted, however, that the wider adaptation community, including the IPCC, uses mitigation to refer to "human intervention[s] to reduce emissions or enhance the sinks of greenhouse gases" (IPCC, 2018). The report uses mitigation in the former sense (as adopted by the disaster risk community).

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" (IPCC, 2014).

Resilience: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNDRR, 2016).

Vulnerability: "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" (UNDRR, 2016).

The goal of *adaptation* is to reduce the potential harms that could result from climate change or to take advantage of emerging opportunities created by a changing climate (IPCC, 2018). Disasters are clearly one of the possible sources of harm from climate change; adaptation therefore includes actions taken to avoid or reduce the negative impacts from these events. The concept of *disaster risk reduction* includes the full range of actions involved in "preparing for, preventing, responding to, and recovering from disasters" (UNDRR, 2016).

In Canada, the term "emergency management" has historically been used to describe activities within preparedness and response. However, in line with Canada's signing of the UN *Sendai Framework for Disaster Risk Reduction 2015–2030* (hereafter referred to as the Sendai Framework), the federal, provincial, and territorial (FPT) *Emergency Management Strategy for Canada* expanded the definition of emergency management to bring in elements of DRR (MREM, 2017). To keep terminology consistent with international definitions, the Panel chose to rely on the more commonly used, narrow definition of emergency management as referring to actions and actors working in the more traditional areas of preparedness and response. The exception to this will be in reference to documents such as the *Emergency Management Strategy for Canada* or when discussing the titles of departments, ministries, or professionals whose roles might go beyond preparedness and response.

The concept of risk is central to both adaptation and DRR. In the context of disasters and climate change, risk is often framed as a function of *hazard, exposure,* and *vulnerability* (IPCC, 2012).[1] *Hazards* are processes or phenomena that have the potential to cause damage or harm to people and the built environment. Extreme temperatures, heavy precipitation, flooding, high winds, and wildfires are examples of hazards. The ability of hazards to cause harm, however, is shaped by exposure and vulnerability. *Exposure* corresponds to the extent to which people, assets, or communities are found in a hazard-prone location (e.g., the presence of housing or buildings in a floodplain or communities located in an area prone to tornados). *Vulnerability* reflects the susceptibility of people or communities to harm, taking into account their characteristics and coping capacity. Among individuals or communities, for example, vulnerability is a function of factors including, but not limited to, the state and quality of physical infrastructure, socio-economic characteristics, social capital and connectedness, health status and age, and institutional preparedness (IPCC, 2012; UNDRR, 2016).

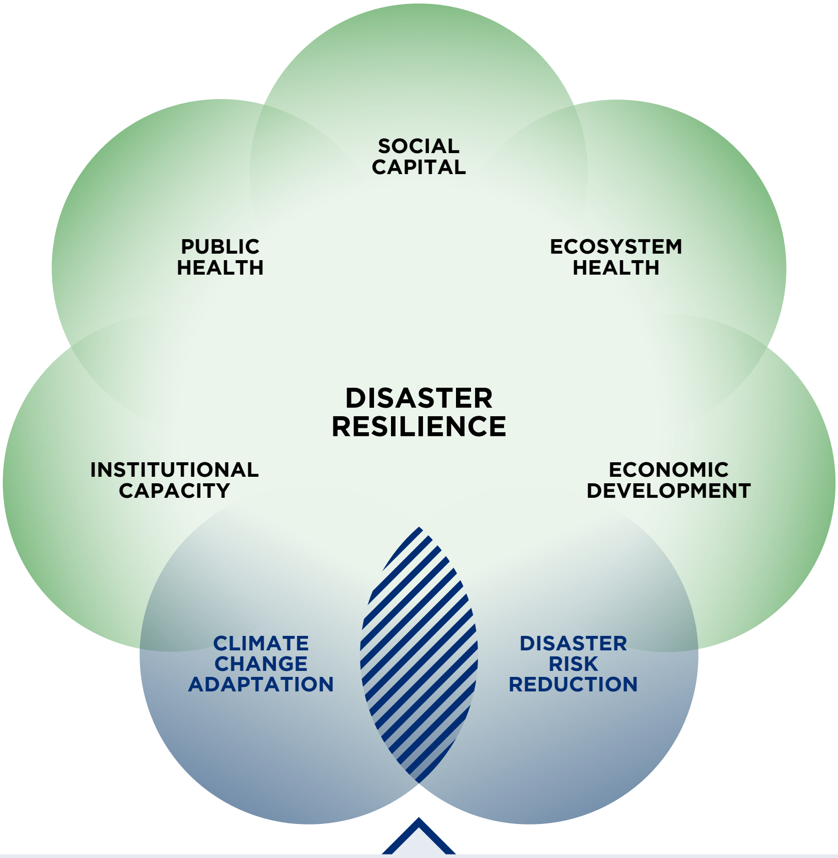
1 Some literature describes risk as a function of only hazard and vulnerability, including exposure as a component of vulnerability (Kelman, 2018).

The Panel underscores that hazards such as floods and wildfires are sometimes inevitable, but "disasters are often the result of planning decisions that put people and property in harm's way" (Bogdan *et al.*, 2020). Even after wildfires and flooding severely impacted Fort McMurray, communities such as Waterways were rebuilt in the floodplain, despite the knowledge of ongoing risk (Bogdan *et al.*, 2020). In May of 2020, Fort McMurray flooded again, causing the evacuation of 13,000 people and resulting in an estimated $100 million in damages and one death (Antoneshyn, 2020; Bogdan *et al.*, 2020). To the extent that a disaster is a consequence of choices by governments, institutions, and individuals, the Panel notes that it is misleading to refer to disasters as *natural*, and so the report refrains from using the term *natural disaster* and instead simply uses *disaster* to refer to the consequences of the meteorological events discussed throughout. In situations where specific data are being described, the term *climate-related disaster* is used for accuracy.

1.2.2 Scoping Decisions

DRR and adaptation are two among several areas of work that are essential to building disaster resilience. Numerous analyses of disaster resilience have recognized its underlying determinants, highlighting factors such as social capital, public health, economic development, and institutional capacity (U.S. National Research Council, 2012; Rockefeller Foundation & ARUP, 2014; Hill & Martinez-Diaz, 2020). The Panel recognizes that making strides in these other areas will in turn aid efforts to advance both adaptation and DRR and contribute to enhanced resilience. However, a detailed investigation into these complementary areas is outside the scope of this report. This report focuses on the areas where the integration of DRR and adaptation are most warranted, including the actions that need to take place; the information, funding, investment, and insurance supports that are required; and the governance processes that will best enable progress. Figure 1.1 situates the area of focus for this report within this broader context of disaster resilience.

Over the course of this report, the Panel's analysis focuses on disasters brought about by sudden weather events (severe storms, temperature extremes, tornados, ice storms, winter storms, and floods) and wildfires where climate and weather can be contributing factors. Climate change mitigation (i.e., GHG emission reduction policies and actions), although important for long-term reduction of risk, was not included in the report.



Reducing Disaster Risk in a Changing Climate

Information

- Availability and accessibility
- Risk assessment
- Indigenous and Local Knowledge
- Risk communication

Funding, Investment, and Insurance

- Build forward better
- Expanded insurance
- Enhanced incentives

Operationalizing Integration

- Whole-of-society collaboration
- Local and Indigenous leadership
- Regulation and legislation
- Codes and standards

Figure 1.1 Report Scope

Building resilience requires more than just the integration of climate change adaptation and DRR. Although institutional capacity, public health, social capital, ecosystem health, and economic development are crucial for enhancing overall resilience, this assessment focuses on the overlap between DRR and adaptation and identifies some key opportunities for integration. To take advantage of these opportunities, significant activity within the realms of information, funding, investment, and insurance must be supported and operationalized through whole-of-society collaboration, local leadership, and well-enforced legislation.

The Panel further recognizes that many elements of DRR and adaptation do not call for integration. Adaptation includes actions taken to adjust to gradual or ongoing changes in the climate that may not lead to events that qualify as disasters. Assisting the migration of tree species northward and upslope to more favourable climate conditions and farming different agricultural crops that will be more successful in emerging and future climate conditions are both examples of adaptation activities that were outside the scope of this report. In DRR, activities occurring during or immediately after a disaster (e.g., paramedic services, firefighting, evacuation) do not offer as many opportunities for integration as those in the lead-up to or recovery from a disaster. Therefore, the report emphasizes interventions upstream and farther downstream of an event rather than the immediate response.

1.2.3 Capability-Based Planning

Capability-based planning is being adopted by FPT governments to coordinate efforts to enhance disaster resilience (GC, n.d.). With origins in military planning, capability-based planning is defined as "planning, under uncertainty, to provide capabilities suitable for a wide range of challenges while working within an economic framework that necessitates prioritization and choice" (Davis, 2002). It recognizes and manages uncertainty, emphasizing reliance on the transferable capabilities that form building blocks that can be reconfigured depending on the specific needs of each circumstance (Davis, 2002; U.S. National Research Council, 2005).

Within the Government of Canada, capabilities are defined as "categories or logical grouping of functions to support our shared EM [emergency management] outcomes" (GC, n.d.). Each capability can be assessed in terms of *competency* (i.e., do we have the skills/knowledge?) and *capacity* (i.e., how much can be delivered?) (GC, n.d.). To maximize the efficiency of DRR investments, the primary focus is on fostering capabilities that are common to all types of disasters, and these efforts are then supplemented with hazard-specific additional capabilities (MREM, 2017). The Government of Canada, provinces, and territories have identified a set of 37 core capabilities in alignment with the 5 priorities for enhancing Canadian resilience through to 2030, as identified by the FPT Ministers Responsible for Emergency Management (Table 1.1).

In the Panel's view, the lack of implementation guidance and communications materials describing these capabilities and their potential application in support of planning limits their utility. It is unlikely that decision-makers outside of FPT governments would benefit from them in their current form. It is also unclear how FPT governments are using capability-based planning to advance their work.

Table 1.1 Canadian Core Capabilities List

Enhance whole-of-society collaboration and governance to strengthen resilience	• Whole-of-society interoperability • Whole-of-society governance • Whole-of-society collaboration • Indigenous collaboration
Improve understanding of disaster risks in all sectors of society	• Risk assessments • Intelligence information sharing • Hazard monitoring and early warning • Public information and awareness
Increase focus on whole-of-society disaster prevention and mitigation activities	• Critical infrastructure resilience • Property resilience • [Emergency Management] planning • Security and interdiction • Structural risk reduction measures • Non-structural risk reduction measures • Natural environment risk reduction measures
Enhance disaster response capacity and coordination and foster the development of new capabilities	• Emergency public alerting • Emergency evacuation and transportation • Operational safety and security • Specialized response resource – disaster search and rescue • Specialized response resource – Hazmat / CBRNE [Chemical, Biological, Radiological, Nuclear and Explosive] • Specialized response resource – flooding • Specialized response resource – wildland interface fire • Public health and emergency medical services • Operational coordination • Operational communications • Emergency legal and financial advice • Emergency logistics • Emergency social services • Fatality management service • Training and education • Exercising
Strengthen recovery efforts by building back better to minimize the impacts of future disasters	• Critical infrastructure restoration • Psychosocial health • Environmental restoration • Cultural restoration • Economic recovery • Property recovery

Source: GC (n.d.)

FPT Ministers Responsible for Emergency Management have established a list of core capabilities applicable to a wide range of disasters. These capabilities are functional groups created to provide a common language to describe the foundational aspects of emergency management. They describe tasks that support shared outcomes across the emergency management system.

The Panel notes that this framework appears mostly grounded in technical capabilities needed in the immediate aftermath of a disaster. Efforts to extend the framework to disaster prevention, mitigation, and recovery appear relatively superficial and fail to indicate tangible areas of expertise. For instance, it is unclear how *whole-of-society interoperability* could be enacted to enhance resilience. Similarly, the inclusion of nebulous capabilities such as *whole-of-society governance* is problematic. Capabilities such as *critical infrastructure resilience* or *structural risk reduction measures* encompass a wide range of underlying approaches, knowledge, and skills; therefore, specificity would be challenging. The Panel also observes that capabilities related to adaptation are not adequately reflected in this approach. In light of these concerns, rather than working within this framework, the Panel instead focuses on more narrow and technical areas of expertise and training that can contribute to improving DRR in a changing climate. These are highlighted throughout the report.

1.2.4 Sources of Evidence

The Panel considered several sources of evidence. Preliminary academic literature reviews related to disasters in Canada, DRR, adaptation, and Indigenous and Local Knowledge (ILK) were performed to initiate the research process. The results of these structured searches ensured that major areas of research were identified and used to build the evidence base for later Panel work. These reviews were supplemented by ongoing research activities and Panel suggestions as the report was developed.

Given the important role of government policy in guiding resilience practices, grey literature documenting Canadian government and international policies and programs played a critical role in developing this report. Synthesis reports from the IPCC (IPCC, 2012), the U.S. Global Change Research Program (USGCRP, 2018), and the United Nations Office for Disaster Risk Reduction (UNDRR, 2019) informed the Panel's analysis, providing extensive bibliographies that were subsequently used to identify further evidence.

No new research was commissioned for this report; however, several experts outside of the Panel were invited to share their experiences and knowledge. Information gained from these presentations was used to address gaps in the published evidence, advance the research, and deepen the Panel's understanding, insights, and deliberations.

1.3 Impacts and Implications of COVID-19

Risks from natural hazards did not lessen during COVID-19, and emergency response activities had to continue despite the already strained capacities and resources (Phillips *et al.*, 2020). These concurrent disasters resulted in increased vulnerabilities and cascading problems, such as those observed during the 2020 wildfires in California (Stern, 2020). Simultaneous stay-at-home and evacuation orders were issued for fire-prone areas, exacerbating confusion for vulnerable populations (Stern, 2020). Smoke from these wildfires contributed to very poor air quality in Canadian cities such as Vancouver, where even sheltering indoors was insufficient to filter out particles (Miljure, 2020). Wildfire smoke contributes significantly to air pollution, which has been shown to negatively affect lung functioning for years following exposure (Orr *et al.*, 2020). There are concerns that air pollution could worsen health outcomes for those infected with the virus (Fahys, 2020; BCLA, 2021).

Adaptation and DRR have also been explicitly acknowledged in relation to COVID-19 recovery stimulus funding under the umbrella of enhancing resilience to future disasters. In August 2020, the federal government announced a new COVID-19 resilience funding stream as an offshoot of the Investing in Canada Infrastructure Program, with a maximum total value of $3.3 billion available to be reallocated from other streams (INFC, 2020a). These funds can be applied to "disaster mitigation and adaptation projects, including natural infrastructure, flood and fire mitigation, and tree planting" (INFC, 2020a). A focus on climate resilience in the recovery from the pandemic has further been reflected in the final report and recommendations by the Task Force for a Resilient Recovery (TFRR, 2020). This report recommends significant investments in natural infrastructure, Indigenous-led sustainable infrastructure, and climate-aware codes and standards to promote resilience to extreme weather events.

1.4 The Structure of the Report

The report is structured as follows:

Chapter 2 positions the report in the context of current disaster and climate trends, identifies government roles and responsibilities, and makes the case for integration between DRR and adaptation.

Chapter 3 explores key activities for affecting hazards and reducing exposure and vulnerability through the integration of DRR and adaptation.

Chapter 4 focuses on the role of integrated information resources for enhancing resilience.

Chapter 5 addresses the importance of integration in public funding, financial markets, and insurance.

Chapter 6 discusses opportunities for operationalizing integration to enhance disaster resilience.

Chapter 7 presents the Panel's final reflections on the charge.

2

Context and Motivation

2.1 Disaster Risk Reduction

2.2 Climate Change Adaptation

2.3 Integrating Disaster Risk Reduction and Climate Change Adaptation

2.4 Conclusion

Chapter Findings

- Climate-related disasters are on the rise in Canada, as are the associated costs. Climate change is a contributing factor, increasing the frequency and severity of natural hazards in Canada.
- Due to significant overlap between DRR and adaptation, integrated approaches to program delivery offer efficiencies while enhancing effectiveness. However, existing organizational structures and processes make it difficult to achieve such integration.
- Motivating factors and cognitive biases common to both DRR and adaptation underscore the value of a shared approach to enhancing resilience moving forward.

Disaster risk reduction and adaptation efforts have historically been addressed through distinct initiatives undertaken by separate groups, but the interconnected nature of these two areas of work is increasingly being recognized. This chapter situates the Panel's work in the context of observed trends in disasters and climate, describes contemporary public sector roles and responsibilities for DRR and adaptation, and presents the overall rationale for enhancing integration between these two domains.

2.1 Disaster Risk Reduction

The nature and extent of disaster risks change over time based on factors such as human settlement patterns, wealth accumulation, and climate change. This section outlines these disaster trends, the associated economic impacts, and the potential impacts of climate change on future disaster risks. This section also describes how roles and responsibilities for DRR are distributed in Canada.

2.1.1 Disaster Trends

The frequency of recorded climate-related disasters in Canada is increasing

Canada's extensive landmass and climatic and geographic variability make the country susceptible to a wide range of climate-related hazards, including extreme hot and cold temperatures, floods, droughts, wildfires, winter storms, freezing rain, hail, tornados, avalanches, and landslides. But hazards only become disasters when they cause damage to people and/or assets. The Canadian Disaster Database (CDD) identifies disasters as events in which 10 or more people are killed or 100 or more people are affected, injured, evacuated, or left homeless, among other criteria (PS, 2019a). Using data from the CDD, Figure 2.1 shows long-term trends in the frequency of these types of disasters by decade since the early 1900s (PS, 2019a). Up until the 1960s, Canada was averaging fewer than 30 climate-related disasters per decade. However, starting in the mid-century, there was an increase in the frequency of these types of disasters, and in recent decades, Canada has experienced over 100 disasters per decade. The Panel notes, however, that the CDD is only periodically updated and the most recent data available is for 2019; weaknesses in Canadian disaster data are discussed in Section 4.1.1. In addition, long-term trends in disaster frequency and impacts should be interpreted with caution, given that data collection is not standardized (PS, 2019a).

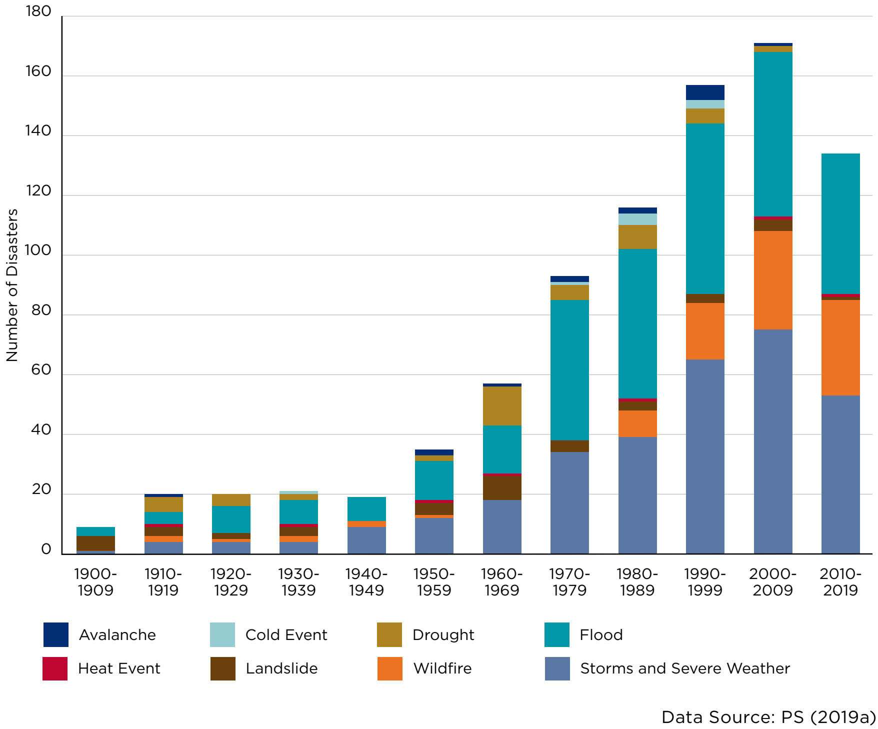


Figure 2.1 Frequency of Climate-Related Disasters in Canada

The figure includes all climate-related disasters recorded in the CDD (these disasters are primarily reported as natural — meteorological) from 1902 through 2019 (PS, 2019a). The storms and severe weather category includes disasters classified as hurricanes/typhoons/tropical storms, storm surges, storms and severe thunderstorms, tornados, winter storms, and unspecified/other storms. Data for the most recent decade may be incomplete due to delays in data entry.

Aerialphotographs.ca / Greg Marshall

Figure 2.2 Flooding of the Ottawa River on the Ontario–Quebec Border, Spring 2019

Much of the increase in disaster costs over time can be attributed to growing exposure. Since 1960, Canada's population has more than doubled, and Canada's economy has increased more than six-fold (World Bank, 2020). The increase in people and assets has led to a consequent rise in exposure to natural hazards. Changing land uses have also contributed to growing exposure, for instance, through the expansion of human settlements and industrial activities into more forested areas at greater risk of wildfires (Peter & Wang, 2006). Due to impermeable surfaces, urban areas tend to have a much lower capacity to absorb stormwater, resulting in significant runoff (ECO, 2018).

Floods and wildfires are among the most common disaster types in Canada. Thirty-seven percent of climate-related disasters recorded in the CDD are floods (PS, 2019a). Since the 1990s, Canada has experienced, on average, five flood-related disasters per year (PS, 2019a). Approximately 8,000 wildfires occur each year in Canada, burning around 2.5 million hectares on average (NRCan, 2019). According to the CDD, 101 wildfire-related disasters occurred in Canada between 1900 and 2016, collectively accounting for 372 fatalities, the evacuation of over

400,000 people, and damages in excess of $5.8 billion (PS, 2019a). The frequency of wildfire-related disasters has also been increasing in recent decades. Prior to 2000, these incidents occurred on average roughly three times per decade. Since 2000, however, they have occurred roughly three times per year on average. While heat events are relatively rare, they account for a high number of fatalities, numbering 548 since 2000 (PS, 2019a).

The Panel underscores that in Canada disasters are defined and recorded based on set thresholds (e.g., the number of people affected or lives lost, the extent of economic losses). One consequence of this type of definition is that formally defined disasters do not occur in areas where there are few or no human interests at stake (UNHRC, 2014). In the Canadian context, this means that sparsely populated regions with lower densities of high-value assets are less likely to experience an official disaster as a result of a hazardous event, even though that same event may be classified as a disaster in more populated areas (NRTEE, 2009). Indigenous people are more likely to live in rural areas than other people in Canada (OECD, 2020b), and Indigenous communities are disproportionately impacted by hazards. Analysis of wildfire evacuation data demonstrates that between 1980 and 2020, roughly 30% of all evacuees were First Nations, while this group represented on average less than 3% of the population of Canada during this period (StatCan, 1998, 2015, 2019; CFS, 2020). However, the CDD's definition of a *disaster* obscures this reality.

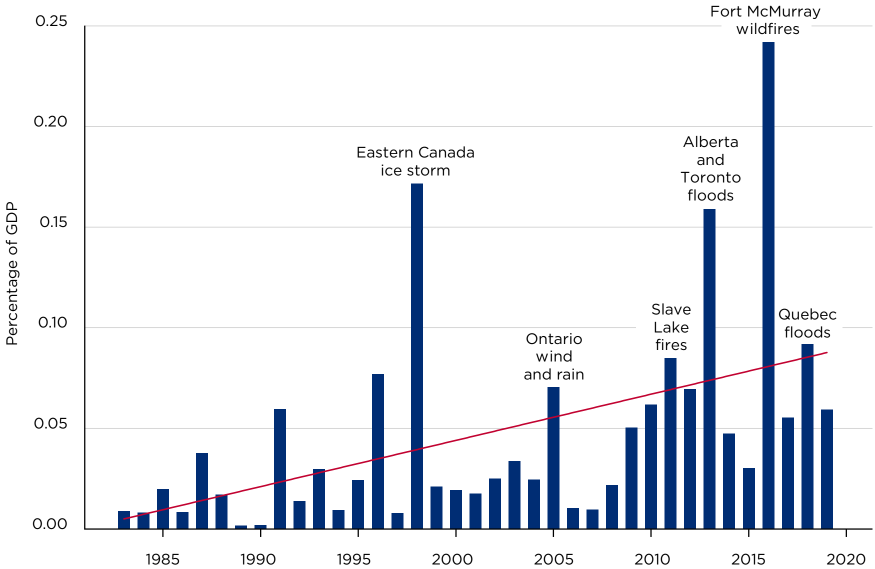
Also absent from this definition are the health and social impacts of disasters. Psychological stresses, including depression, anxiety, grief, and even post-traumatic stress disorder, are well-documented impacts of disasters (Padhy *et al.*, 2015; Bubeck *et al.*, 2017). Physical health impacts include injury or longer-term impacts like illness from contaminated water or the exacerbation of pre-existing chronic conditions (Thieken *et al.*, 2016). Bubeck *et al.* (2017) offer a typology of impacts, distinguishing between those that are direct and indirect, and those that are tangible and intangible. Intangible impacts are sometimes not quantifiable and often cannot be monetized, as is the case with losses of cultural heritage (Wagner & Weitzman, 2015; Bubeck *et al.*, 2017).

The economic impact of climate-related disasters is increasing in Canada

Estimates of the total economic costs of disasters are often subject to considerable uncertainty, and damages are likely underestimated due to knowledge gaps (e.g., understanding of how multiple hazards may interact and how damages may cascade across the economy) and the difficulty of monetizing certain kinds of losses (e.g., ecosystems, health impacts) (Sawyer, 2020). Despite these limitations, the evidence suggests that these estimated costs are rising over time in Canada. Little information exists on the economic costs of disasters prior to the 1950s. Based on data from the CDD, economic losses from these events started to increase steadily in the 1970s and continued to grow throughout the 1980s and 1990s, reaching a high point in the latter part of that decade with the widespread damage that occurred during the 1998 ice storm in Eastern Canada (PS, 2019a). After moderating in the early 2000s, costs are now rising again due to events such as the floods in Calgary in 2013 and the wildfires in Fort McMurray in 2016.

The increasing cost of disasters includes both insured losses and costs to the governments providing assistance in the wake of these disasters. The federal Disaster Financial Assistance Arrangements program has seen its liabilities and payments increase substantially and exceed its nominal annual appropriation of $100 million (PBO, 2016). Average payments since 2010 have equalled over $330 million annually, with outstanding federal liabilities of $2.6 billion (PS, personal communication 2021). The 2021 federal budget recognized the need to provide further funding, committing $1.9 billion over five years beginning in 2021–22 (GC, 2021c).

Increases in population and gross domestic product (GDP) are both major contributors to growing economic damages (Sawyer, 2020; Frank *et al.*, 2021). While the absolute cost of climate-related disasters around the world is increasing over time, analyses that normalize global disaster costs relative to the size of the economy have found either no significant trend (Barthel & Neumayer, 2012) or declining disaster costs as a share of GDP (Pielke, 2019). However, for some countries (including the United States), these costs are rising relative to the size of the economy (Barthel & Neumayer, 2012). Data on insured losses from disasters in Canada indicates that this is also the case for Canada. Figure 2.3 shows insured losses as a percentage of Canadian GDP between 1983 and 2019. While variable from year to year, insured disaster losses as a share of Canadian GDP are increasing over time.



Data Source: StatCan (2016) and IBC, personal communication (2020)

Figure 2.3 Insured Losses from Climate-Related Disasters in Canada, as a Share of GDP: 1983–2019

Insured losses from disasters are growing over time as a share of GDP. This figure captures a range of weather-related disasters, including forest fires, as compiled and shared by the Insurance Bureau of Canada from various sources. Data from 1983 to 2007 are drawn from the Insurance Bureau of Canada, Public Safety Canada, Swiss Re, and Deloitte. Data from 2008 to 2019 are based on loss data compiled by CatIQ. GDP data were retrieved from Statistics Canada. The trend is statistically significant (r^2=0.24; $p<0.01$).

Insured losses also represent only a fraction of the total economic costs created by disasters. For example, lost income, mental health consequences, and some property losses are typically excluded from insurance coverage (Sawyer, 2020). While the "insurance gap" (i.e., the share of uninsured losses) is shrinking over time, global reinsurance provider Munich Re estimates that still less than half of all disaster-related losses are insured in industrialized countries, and the proportion of insured losses in developing and emerging economies is below 10% (Munich Re, 2020). This is concerning from an equity standpoint, as those who can least afford to bear the burden of a disaster are also the least likely to be able to afford insurance. Measuring losses in absolute terms rather than as a share of household assets ignores the equity dimension of disasters. Kelman (2020) points out that aggregate financial loss data "do not fully reflect what people endure in disasters," and when a very affluent household loses 20% of its wealth, this has less serious implications than a low-income household losing that same share.

Concurrent, cascading, and non-linear impacts of disasters are increasingly likely in a changing climate

In a previous report, the CCA's Expert Panel on Climate Change Risks and Adaptation Potential observed that "major climate change risks are complex and interconnected, and negative impacts can propagate through natural and human systems in ways difficult to anticipate" (CCA, 2019b). The complexity and unanticipated consequences of some risks complicate matters and warrant consideration in risk assessments (Clarke *et al.*, 2018; CCA, 2019b). This could manifest in a variety of ways (Figure 2.4).

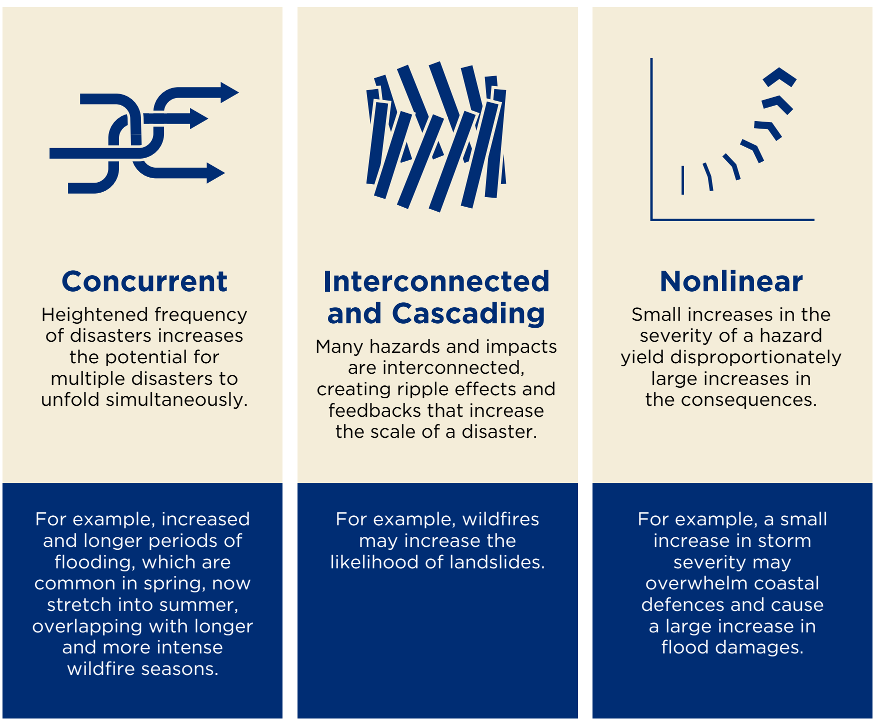


Figure 2.4 Concurrent, Cascading, and Nonlinear Disaster Risk

In a changing climate, it is increasingly likely that disasters could unfold simultaneously, cascade in ways that add to their overall impacts, and demonstrate increasingly large consequences from small increases in hazards.

First, as the frequency of disasters grows, so too does the potential for multiple *concurrent* disasters (Mora *et al.*, 2018). In Canada, disasters are much more common in the spring and summer compared with other times of the year, exacerbating the potential for overlapping events (Clark, 2020). Flooding is the most prevalent disaster type in the spring and, as the season approaches summer, wildfires and storms also become more frequent (Clark, 2020). This was the case in Canada in 2013 when the insurance sector faced a shortage of insurance adjusters when they were required to process claims from major flooding events that took place in both southern Alberta and the Greater Toronto Area, alongside the Lac-Mégantic rail disaster (Meckbach, 2020). The combination of COVID-19 and wildfires in California in 2020 is another example of two distinct disasters that each worsened the other (Section 1.3).

Second, many hazards and impacts are *interconnected*, and in many instances, a failure in one place could cause *cascading* failures elsewhere, increasing the potential overall impact of a disaster. Where these interconnections are poorly understood, risks are likely to be underestimated (CCC, 2016). One hazard could increase the likelihood of another one — for instance, when a wildfire increases the likelihood of a landslide or flood (USGS, n.d.). In the summer of 2021, Lytton, British Columbia, broke records for the highest temperature recorded in Canadian history for three consecutive days, reaching 49.6°C and making it extremely susceptible to the fire that tore through and mostly destroyed the village (Blaze Baum *et al.*, 2021; Isai, 2021). Cascading impacts are also widely reported. Critical infrastructure is recognized as one place where these interdependencies could be significant (MREM, 2017). This was the experience during the 2017 Hurricane Harvey in Houston, Texas, when more than 300,000 customers lost power, a quarter of all oil production along the U.S. Gulf of Mexico halted, and hospital operations were strained (ERCOT, 2017; Scheyder & Seba, 2017; THA, n.d.).

Third, there is mounting evidence of *nonlinearities* wherein small increases in the severity of a hazard yield relatively large increases in the consequences (Burke *et al.*, 2015; Hsiang *et al.*, 2017; Coronese *et al.*, 2019). Based on international data gathered from individual emergency events between 1960 and 2015, Coronese *et al.* (2019) find that the spread between the most and least damaging disasters is growing, with robust evidence of a relatively high increase in the damages from the most extreme events. On a global scale, increases in GHG concentrations have the potential to bring about "self-reinforcing cycles or feedbacks within the climate system [which] have the potential to amplify and accelerate human-induced climate change" (Hayhoe *et al.*, 2018). Examples of these state changes include the collapse of the West Antarctic ice sheet, coral bleaching, and destabilization of the Amazon and boreal forests (Lenton *et al.*, 2019; Pörtner *et al.*, 2019). In its most recent assessment, the IPCC reports that "low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed very likely range of future warming cannot be ruled out and are part of risk assessment" (IPCC, 2021).

2.1.2 Roles and Responsibilities

Policy direction for DRR in Canada is established jointly by the FPT Ministers Responsible for Emergency Management in *An Emergency Management Framework for Canada*. This framework guides four components of emergency management: prevention and mitigation, preparedness, response, and recovery (MREM, 2017). It uses an all-hazards approach, which proposes that many of the elements of DRR are generic rather than hazard-specific (MREM, 2017). Building on this framework, the *Emergency Management Strategy for Canada* establishes five priority areas of work leading up to 2030: whole-of-society collaboration and governance, strengthening understanding of disaster risks, prevention and mitigation, response capacity and coordination, and building back better (GC, 2019b). This strategy is aligned with the Sendai Framework, the key policy document guiding international efforts, to which Canada is a signatory. Adopted in 2015, the Sendai Framework is intended to guide DRR efforts out to 2030 (UNISDR, 2015). Particular areas of alignment between the Sendai Framework and the *Emergency Management Strategy for Canada* include an emphasis on whole-of-society approaches and building back better.

In practice, many of the responsibilities related to DRR sit at the municipal level. Municipalities are the first in line to respond in the event of a disaster and also have the best understanding of the local context (Juillet, 2013). Other orders of government may be called on to step in as needed (MREM, 2017) (see Section 6.1.3 for further discussion of local leadership).

First Nations governments play a primary role, working at the community level across the spectrum from prevention to recovery (HoC, 2018). Indigenous Services Canada administers funding programs that provide support to First Nations communities (but not Métis or Inuit communities) for disaster prevention, mitigation, response, and recovery (ISC, 2019b). Indigenous Services Canada also ensures the availability of additional emergency response capacity for First Nations communities when disasters exceed local response resources; the federal government often contracts with provincial and territorial governments to provide this additional capacity (HoC, 2018). Recent investigations have found that, in practice, respective roles and responsibilities are poorly defined, funding is inadequate, and First Nations' expertise is undervalued (HoC, 2018; Verhaeghe *et al.*, 2019). Reconciliation — in particular, the commitment to work towards the adoption of the United Nations Declaration on the Rights of Indigenous Peoples, which includes provisions for self-determination — provides further impetus for change (GC, 2021a).

Lands are co-managed across Inuit Nunangat, and territorial governments all have emergency management responsibilities (Funston, 2014). Legislation varies across the three territorial governments but generally recognizes the primary role of local communities in emergency planning and response. Communities are typically required to understand their own risks and have appropriate plans in place. In practice, as an emergency unfolds, all orders of government can be implicated in different ways, resulting in unclear responsibilities (Funston, 2014). A lack of information and analysis on disaster risk management responsibilities, needs, programming, and perspectives from Métis and Inuit communities was a recurring theme in the Panel's research, and the roles of Métis and Inuit governments in DRR remain relatively unclear.

2.2 Climate Change Adaptation

Observed climate trends and future projections inform the nature and extent of the influence of climate change on disaster risks. This section outlines these trends and projections, summarizes the science of disaster event attribution research, and describes how adaptation roles and responsibilities are currently distributed in Canada.

2.2.1 Climate Trends and Projections

Climate change will increase the frequency and severity of natural hazards in Canada

Canada's climate is changing. Zhang *et al.* (2019) report that "Canada's mean annual temperature [has] risen about 1.7ºC (likely range 1.1ºC–2.3ºC) over the 1948–2016 period" — and the majority of this observed warming is attributable to human activities. Ocean surface temperatures in the Northeast Pacific and most of the Northwest Atlantic have also risen, consistent with human-caused climate change (Greenan *et al.*, 2019). Ongoing changes in Canada's climate will continue to alter the frequency and severity of climate-related natural hazards as global GHG emissions rise. Risks related to extreme heat, wildfires, drought, and coastal and inland flooding are expected to increase in the coming decades, with even greater increases expected later in the century in high-emission scenarios (Flato *et al.*, 2019). Even if global GHG emissions are rapidly reduced, these risks will still increase in the coming years as temperatures continue to rise because of past emissions (Flato *et al.*, 2019).

Temperature extremes are strongly linked to changes in mean temperature, and as Canada warms, extreme temperature highs will increase in frequency and intensity.[2] Heat waves are likely to be more frequent and more severe (Zhang *et al.*, 2019). The length of fire seasons and the severity of wildfire weather are projected to increase in Canada due to climate change (Wang *et al.*, 2017; Wotton *et al.*, 2017; Zhang *et al.*, 2019). Increased temperatures will also contribute to further permafrost warming and thawing (Derksen *et al.*, 2019).

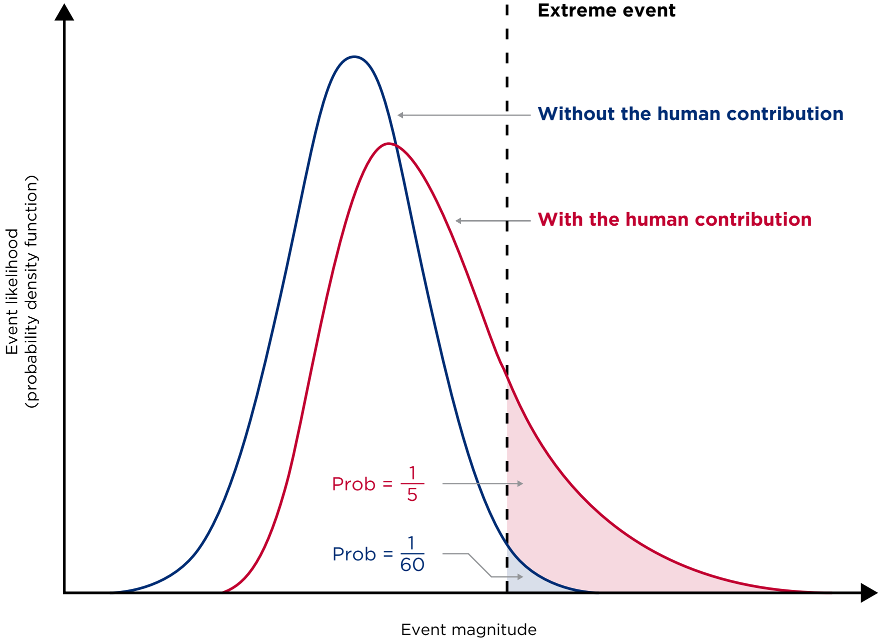
The impact of climate change on flooding risks is complex. Climate models project that extreme precipitation events will become more frequent in both low- and high-emission scenarios, driven by the Clausius-Clapeyron relationship, which finds that warmer atmospheres are able to hold more water (roughly 7% more with each 1°C increase in temperature) (Westra *et al.*, 2014; Zhang *et al.*, 2019). The increased likelihood of short-duration, high-intensity rain events will increase flooding risks in urban areas, as surfaces are less able to rapidly absorb and channel large amounts of rainfall (Bonsal *et al.*, 2019). More frequent heavy precipitation events may also increase the risk of precipitation-induced landslides. Many coastal areas will be increasingly susceptible to flood risks due to rising sea levels (with changes in risk varying based on localized rates of the land subsiding or rising) and decreases in protective ice cover (Greenan *et al.*, 2019). Excess moisture in late fall, followed by frozen soil conditions in winter, is a known mechanism that leads to excess runoff resulting in flooding during the spring melt (Zahmatkesh *et al.*, 2019). The increased frequency of winter thaws may also raise flood risks associated with ice jams in Canada (Bonsal *et al.*, 2019). However, it is uncertain how changes in precipitation patterns and ice and snow cover will affect flooding related to the snow-melt (Bonsal *et al.*, 2019).

Climate models project a global increase in the intensity of storms due to the increased thermal energy in the atmosphere; however, projections in the regional distribution of storm activity remains highly uncertain (Greenan *et al.*, 2019). Hurricanes are expected to experience slower rates of decay as they make landfall and thus pose a greater threat inland (Li & Chakraborty, 2020). Reduced sea-ice cover will increase risks from storms and storm surges in some areas of the Arctic and Atlantic Canada (Greenan *et al.*, 2019). Climate change may also increase risks from freezing rain and hail in some regions of Canada (Cao, 2008; Klima & Morgan, 2015).

2 The highest daily temperature that is currently reached once every decade may be met every two years in a high-emission scenario, for example. Additionally, hot days (where the maximum temperature exceeds 30°C) will become more frequent (Zhang *et al.*, 2019).

Disaster event attribution research demonstrates the influence of climate change on mounting disaster risk

Climate scientists and researchers are increasingly using climate models to investigate the extent to which climate change is making events of a given magnitude more likely (Swain *et al.*, 2020). Techniques have been developed to reasonably attribute various types of extreme weather events to climate change in a statistical sense (i.e., the probability of seeing a specific extreme is so low without climate change that it is reasonable to assume climate change has played a major role) (Swain *et al.*, 2020). In attribution studies, climate models are used to compare the likelihood of weather events (or classes of weather events) in scenarios with anthropogenic warming (i.e., human-induced climate change) versus scenarios without anthropogenic warming (Figure 2.5) (Zhang *et al.*, 2019).



Courtesy of Environment and Climate Change Canada (ECCC)

Figure 2.5 Event Likelihood With and Without Climate Change

This graph shows the estimated probability distribution for an extreme event both with climate change (red line) and without (blue line). In a changing climate, the likelihood distribution widens with a relatively greater likelihood of the most high-impact events. The shaded region represents the increase in probability due to warming, with this example showing a 12-fold increase in the probability of events over a certain threshold of intensity in the presence of climate change.

Studies of this type suggest that climate change made some recent climate-related events in Canada more likely. Teufel *et al.* (2017) found that, in Alberta, climate change increased the likelihood of extreme rainfall of the type that led to flooding in Calgary and neighbouring communities in 2013 and that extreme rainfall of this type is likely to become much more common by the end of the century in both low- and high-emission scenarios. Teufel *et al.* (2019) found a similar effect when assessing the 2017 floods near Montréal, finding that heavy-rainfall events of the type that led to this flooding are two to three times more likely now than they were in the pre-industrial climate. An analysis of the Ottawa River flooding of 2019 further reinforces these findings (Kirchmeier-Young *et al.*, 2021).

2.2.2 Roles and Responsibilities

The Paris Agreement sets out the international framework governing adaptation (UNFCCC, 2015). As a signatory, the Government of Canada has committed to the global goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change." Within Canada, all governments have responsibilities relating to adaptation. Federal and other orders of government work together in areas of shared or unclear jurisdiction, and the decisions as to which government will lead, which will support, and how this division is implemented may vary across time and place. The *Pan-Canadian Framework on Clean Growth and Climate Change* (Pan-Canadian Framework) was established by FPT governments as a joint plan for addressing climate change both in terms of lowering emissions and adapting to a changing climate (GC, 2016).[3] It focuses on five work areas to build resilience: "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; [and] reducing climate-related hazards and disaster risks." This final work area on disaster risks focuses on infrastructure investments, flood protection measures, and support for adaptation in Indigenous communities (GC, 2016). A 2021 update to Canada's climate change plan reinforces these directions and proposes the development of a national adaptation strategy and the co-development of a distinctions-based[4] Indigenous Climate Leadership Agenda (ECCC, 2021). A national adaptation strategy is under development, drawing from the expertise and perspectives of a wide range of partners and stakeholders (GC, 2021b). Disaster resilience and security has been identified as one of five key themes underpinning this strategy, and the importance of linkages to other policies and programs is recognized (GC, 2021b). The National Inuit Climate Change Strategy identifies Inuit-

3 The original agreement did not include the province of Saskatchewan, and as of 2021 other provinces, including Ontario and Alberta, had also signalled a lack of support for the plan (GC, 2016; ECCC, 2020b).

4 Distinctions-based approaches recognize the need to engage with First Nations, Inuit, and the Métis Nation in ways that recognize the unique circumstances, rights, and priorities of each Peoples (JUS, 2018).

driven priority areas of work and calls for the active engagement of Inuit in shaping policy (ITK, 2019). Recognizing the unique impacts of climate change across Inuit Nunangat, priorities include closing the infrastructure gap and reducing the vulnerability of the food system (ITK, 2019).

As is the case with DRR, Indigenous and municipal governments are often best placed to identify and respond to local adaptation priorities. Community engagement processes can be used to determine key challenges and solutions and involve individuals in community responses (FCM, 2021). All orders of government also play important roles in motivating actions at the individual level through policies and programs (Chapters 5 and 6).

2.3 Integrating Disaster Risk Reduction and Climate Change Adaptation

The IPCC's 2012 special report *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* explores the closely intertwined nature of adaptation and DRR (IPCC, 2012). The potential for adaptation investments to reduce disaster risks and for disaster-related spending to advance adaptation is well-recognized but can be challenging to achieve in practice (GCA, 2019). Existing organizational structures and processes were not developed with this integration in mind, and individual decision-making processes and cognitive biases can interfere with efforts to advance both DRR and adaptation. However, as this section demonstrates, if these challenges can be overcome, the rewards of integration — in terms of both efficiency and effectiveness — can be considerable.

2.3.1 Organizational Impediments

Distinct governance mechanisms create barriers to integration

Barriers to integration include different legal, financial, and jurisdictional structures and are compounded by issues of culture, values, and interests (Nemakonde *et al.*, 2017). Nemakonde *et al.* (2017) observe:

> *DRR and [adaptation] structures have largely developed in parallel, and as a result they mostly operate in isolation. Practitioners addressing DRR and [adaptation] are affiliated to separate organisations and institutions both internationally and nationally. Particularly at (sic) national level, the traditional division of responsibilities into discrete areas has contributed to the location of DRR and [adaptation] in different ministries and administrative units.*

At the federal level, adaptation efforts have been led by Environment and Climate Change Canada (ECCC) and Natural Resources Canada (NRCan), while DRR activities have been led through PS (NRCan, 2017; PS, 2019c). With these arrangements, funding programs rolled out from one of these domains are unlikely to incentivize actions in the other domain without deliberate efforts (Birkmann & von Teichman, 2010). A pan-Canadian audit of FPT governments found "limited coordination [which] led to an ad hoc response to climate change," creating the risk of gaps, duplication, or conflict across policies (OAG, 2018). These findings are not limited to Canada; they are well established in Europe and the United States (Amaratunga *et al.*, 2017). Albris *et al.* (2020) observe that challenges also arise for academics and practitioners working separately on DRR and adaptation, owing to a lack of common engagement opportunities. Established legal mandates for emergency management may further impede integration, as agencies responsible for DRR are often compelled to focus on nearer-term disaster response and recovery rather than longer-term risk-reduction efforts (Amaratunga *et al.*, 2017).

Reliance on different sources of data, definitions, and information impedes communication and interoperability

Differences in the ways that related concepts and terminology are defined and used are one factor contributing to a lack of effective integration between adaptation and DRR (Birkmann *et al.*, 2009). In the climate change community, mitigation is widely used to refer to the reduction of GHG emissions, while in the DRR community, mitigation refers to proactive DRR measures (BCMOTI *et al.*, 2014a). Experiences with climate change vulnerability risk assessments reveal that engineers and climate scientists often use the same language somewhat differently and may not share the same understanding of terms such as climate, data, vulnerability, and adaptation, among others (BCMOTI *et al.*, 2014a).

Birkmann and von Teichman (2010) observe that, "in general, only weak links exist between the different types of knowledge, data and work applied by climate and risk scientists and practitioners, which hinders straightforward communication, collaboration and joint programming." Legal and organizational barriers to information sharing further impede integration (Amaratunga *et al.*, 2017).

Adaptation and DRR activities often function at different scopes and scales, complicating integration efforts

Kelman *et al.* (2017) argue that there are differences in the time scale and the nature of the society–environment interactions in these concepts. DRR considers both long and short time frames, though, in practice, preparedness and response tend to be better resourced, and immediate demands are prioritized relative to longer-term prevention and mitigation activities (see Chapter 5). In contrast, adaptation tends to prioritize long-term trends and actions (Kelman *et al.*, 2017).

In addition, DRR efforts may focus on building the capabilities needed to address a range of disaster risks — some of which are not influenced by climate change (Amaratunga *et al.*, 2017; Chmutina *et al.*, 2017). Conversely, adaptation efforts encompass several disaster risks alongside risks and opportunities associated with more gradual shifts that play out over longer time frames.

2.3.2 Motivating Factors for Adaptation and DRR

Understanding what motivates protective actions for DRR and adaptation is key to building resilience

Several sociopsychological theories exist to explain individual protective behaviours. In the context of flooding, the protection motivation theory characterizes adaptive responses as a function of individual appraisals of flood risks and individual ability to cope (Grothmann & Reusswig, 2006; Kuhlicke *et al.*, 2020). The protective action decision model — a model built around individual responses to environmental risks — posits that in order to pursue a risk-reduction action, individuals must first receive, absorb, and comprehend risk information (Lindell & Perry, 2012). At this point, an individual will consider whether they need to pay attention to a threat, take action in response, and, from there, consider and select among the response options. Other models also consider perceived responsibility, social norms, and the elements needed to turn individual plans into actions (Kuhlicke *et al.*, 2020).

Risk perception plays a key role in shaping individual responses; as described by Agrawal (2018), "[w]hen a person is exposed to a risk, they do not respond to that risk directly; rather they respond to their own perception of that risk." Perceptions are a function of past experience, social context, and advice received from authorities and peers (Agrawal, 2018). The connection between previous disaster experience and risk perception is complex: in some circumstances, past experience can bring about a sense of powerlessness, while in others, it can build a sense of personal efficacy (McGee *et al.*, 2009). Threat immediacy can elicit action; when it comes to pursuing measures to protect against future theoretical disaster risks, the lack of immediacy can lead to procrastination (Lindell & Perry, 2012).

Perceptions of hazard mitigation measures are also important for determining individual responses. Hazard adjustment measures are assessed based on characteristics related to the hazard (i.e., how effective is this measure in providing protection) and the resources required (e.g., cost, effort) (Lindell *et al.*, 2009). In addition, recognizing that individuals face a wide set of risks and concerns, McCaffrey *et al.* (2020) note that actions that offer a range of benefits may receive greater take-up. For instance, wildfire risk mitigation measures such as watering grass, clearing gutters, and installing double-paned windows may be pursued for reasons unrelated to wildfire risk management (McGee, 2005).

Furthermore, decision-making about risk is dependent on social processes and values (Etkin & Ho, 2007). Social learning that occurs from observing behaviours of others can provide important cues and motivate individual protective actions, and community-level collective action provides an important complement to household-level measures. Community cohesion is a key contributor to wildfire preparedness; this cohesion enables learning, supports collective actions that reduce community-level risks, and promotes attachment to place, which in turn motivates protective measures (Prior & Eriksen, 2013). Prior and Eriksen (2013) propose that "paying greater attention to social attitudes, beliefs, values and emotions concerning the environment, and how these are influenced, could inform more effective and lasting solutions to intractable environmental problems that are socially derived."

Lindell and Perry (2012) argue that communications need to address all elements of the protective action decision model in order to motivate immediate actions in response to the message. When some elements are ignored, those on the receiving end of the communications are more likely to seek out further information and delay actions (Lindell & Perry, 2012). McCaffrey (2015) notes that local context is another important element of effective communication, shaping how recipients interpret and act on the information being communicated.

Lieske *et al.* (2014) identify the following features of risk communication that are needed to inspire action: trust in the authorities producing the communication materials; description of specific effective response strategies; emphasis on the efficacy of response options; and appropriate incentives to motivate action. In the context of flood risk communication, MacKinnon *et al.* (2018) identify five key lessons for effective communications: (1) listening to the intended audience, (2) localizing both risks and solutions, (3) linking between specific actions and broader goals, (4) leaning on communities to assume responsibility, and (5) learning about the success of various strategies. Interactive communications processes are also important for bringing about behaviour change (Steelman & McCaffrey, 2013; McCaffrey *et al.*, 2020).

Education is necessary but not sufficient for behaviour change (Luna, 2017). The importance of education is recognized in the Sendai Framework, the Sustainable Development Goals, and the Paris Agreement (Luna, 2017). Sections 4.3 and 5.3 identify key capabilities to be strengthened to enhance disaster resilience in a changing climate, and formal education offers one means of building the requisite skills. Lund University in Sweden appears to be the first to offer a master's degree that has an explicit joint focus on disaster risk management and adaptation (Lund University, n.d.).

Cognitive biases common to DRR and adaptation reinforce the value of taking an integrated approach

Cognitive biases and human behaviour can impede increased resilience, as beliefs, norms, and values can all heavily influence risk awareness and choice of action, even in the face of clear evidence. Kahneman (2011) outlined two decision-making systems that work in tandem to guide human decision-making. System one "thinks fast" to make simple decisions based on instinct, while system two "thinks slow" to make complex decisions in a more deliberate way. Meyer and Kunreuther (2017) note that "as efficient as these intertwined systems may be for navigating the vast majority of situations we confront on a day-to-day basis, they perform very poorly when dealing with problems that are unfamiliar, complex, and temporally distant." Unfortunately, this is exactly the case when it comes to preparing for and preventing disasters — low-probability, high-impact events that are poorly understood. These biases become increasingly problematic in the face of mounting disaster risks in a changing climate. The biases that can influence DRR and adaptation are wide-ranging.

Myopia: The human propensity to sacrifice future well-being in favour of immediate gains is well-documented (O'Donoghue & Rabin, 1999). Given that investments in resilience require people to incur near-term costs for unknown future benefits, myopia undermines a range of actions that could increase welfare over the long term (Linnemayr *et al.*, 2016). This bias is particularly problematic in a changing climate where "myopic forecasts do not incorporate the emerging (but ambiguous) information being generated by climate science" (Kahn, 2015). "Hyperbolic discounting" — wherein individuals would generally favour spending tomorrow over spending today, leading to procrastination in resilience investments — is a distinct challenge that can contribute to the same kinds of choices (Ainslie & Haslam, 1992; Meyer & Kunreuther, 2017).

> "Defaulting to the status quo is particularly problematic in a changing climate where past choices have left society increasingly ill-equipped to face future hazards."

Inertia: Investments in disaster prevention and mitigation tend not to be a default course of action and instead require a deliberate choice (Meyer & Kunreuther, 2017). Defaulting to the status quo is particularly problematic in a changing climate where past choices have left society increasingly ill-equipped to face future hazards. Loss aversion compounds this problem: people suffer more from losses than they benefit from gains and are thus reluctant to part with money for investments in resilience that may not reap a reward (Kahneman & Tversky, 1979).

Optimism: Motivated reasoning leads individuals to imagine the scenarios that they want to see come about (Kunda, 1990). The availability bias, wherein individuals base risk assessments on how readily they can call to mind similar events, tends to reinforce this belief, as most of the events they can recall happened to others (Meyer & Kunreuther, 2017). This bias may be particularly limiting in a changing climate as "we are constantly confronted with new extremes" (Hill & Martinez-Diaz, 2020). Finally, the compounding bias leads people to focus on the risk of an event at a specific point in time rather than the risk that the event will occur at some point over a longer period of time (Meyer & Kunreuther, 2017).

Governments and other decision-makers can establish policies and programs, but unless they factor in the social context in which these policies and programs roll out, they will not be as effective (Meyer & Kunreuther, 2017). When policy-makers recognize and confront these biases — which themselves manifest across society, from the household to the organizational to the political level — they can foster conditions for all of society to engage and participate in preventing and preparing for disasters (Meyer & Kunreuther, 2017). For instance, capitalizing on the salience of recent disasters can be an effective strategy for encouraging long-term resilience investments, particularly when authorities highlight increasing risks due to climate change. The success of Nova Scotia's municipalities in advancing adaptation has been partially attributed to the 2003 experience of Hurricane Juan, which raised the profile of these types of risks and underscored the need for action (Vogel *et al.*, 2020). Explaining risks with deliberate language and changing insurance program design are among the interventions that can help overcome these biases (Sections 4.2.3 and 5.3.2).

2.3.3 The Value of an Integrated Approach

Efficiency: DRR and adaptation share much common ground, and integrated approaches can stretch scarce resources

DRR and adaptation share many goals and activities. They both involve preparing communities for weather events, assessing and managing weather-related risks, designing and locating buildings and infrastructure in ways that reduce risk, enhancing community capacity to manage risks, and recovering from disasters in ways that build resilience. They both also benefit from some of the same information and share similar tools and approaches (e.g., downscaled climate projections, vulnerability assessments). An integrated approach could provide efficiencies by pooling rather than duplicating resources and efforts (IPCC, 2012; Howes *et al.*, 2013).

One example of an integrated approach that could provide significant benefits to both communities is shared risk assessments. Currently, the division of responsibilities across institutions can lead to separate DRR and adaptation-related risk assessments being conducted on the same hazard (Amaratunga *et al.*, 2017). Risk assessments that include climate projections, such as shifting hazards and recurrence intervals, will provide better information for a range of applications, including designing critical infrastructure (Section 4.2.4). Recognizing climate change as one of many disaster risk factors acknowledges the central role of vulnerability in shaping risks and factors in how adaptive capacities may improve or degrade over time. This approach can support the more effective use of scarce resources (Eyzaguirre *et al.*, 2018).

Shared learning can provide efficiencies and improve overall performance. The adaptation community has focused more upstream on prevention and risk reduction and could potentially offer lessons to DRR practitioners who have historically focused more on preparedness, response, and recovery (Eyzaguirre *et al.*, 2018). Both communities have used data but typically at different scales: the traditional reliance of the DRR community on historical data could inform the interpretation of long-term trends, whereas the modelling tools developed in climate science are needed to inform future scenarios (Eyzaguirre *et al.*, 2018). Natural Resources Canada coordinates the Climate Change Adaptation Platform, which works with a range of groups to disseminate tools and information to support adaptation (NRCan, 2020a). One of the products that has been developed under this platform is a collection of best practices for cities adapting to extreme rainfall, salient for both DRR and adaptation communities (Kovacs *et al.*, 2014).

Effectiveness: Coherent DRR and adaptation investments and policies can be mutually reinforcing

When DRR and adaptation policies are created in isolation, conflicting incentives and directions may emerge (U.S. National Research Council, 2012). DRR and adaptation programs may not maximize overall resilience and, at worst, can work at cross purposes. In the United States, hospitals designed to be resilient to extreme weather events failed to appropriately prepare for flood risks. Backup generators were installed to maintain hospital functioning in the event of a power outage, but these generators could not operate due to basement flooding during Hurricane Sandy (Evans & Carlson, 2012). In the case of New York University's Langone Medical Center, the fuel source for the generators was required by code to be kept at the building's lowest level (Klinenberg, 2015). Failure to adequately account for flood risk — which is expected to increase in a changing climate — undermined the value of the DRR measures implemented. A recent study found that 8% of Canada's healthcare centres are at risk of flooding in the event of a 1-in-100-year flood (CICC, 2021). When planning and development controls hinge on floodplain mapping that is based on historical conditions, communities may continue to invest in the development of buildings and infrastructure in locations that will become increasingly flood-prone in a changing climate. Maladaptation is also a concern; in addressing one risk, maladaptive actions inadvertently exacerbate another one (Noble *et al.*, 2014). For instance, flood protection measures based on the current climate may create a sense of safety and lead to further development and exposure of people and assets in flood-prone areas, even though those defences may be inadequate in a future climate.

In contrast, when working together, the adaptation and DRR communities can build overall resilience. The Global Commission on Adaptation identified disaster risk management as one of six key areas in which adaptation actions needed to be accelerated (GCA, 2019). In 2013, the U.S. city of Baltimore initiated a climate change-informed disaster preparedness and planning project to improve resilience across risks, factoring the role of climate change into heat waves, sea levels, precipitation, and flooding (City of Baltimore, 2018). The city's plans focus on preventative measures, noting that they are likely to be less costly than recovery spending. The city reports on progress each year with the ability to make revisions based on lessons as hazards unfold over time; responsibility ultimately lies with the climate and resilience planner. Moving forward, the city plans to integrate human-caused hazards alongside natural hazards to provide a more comprehensive plan (City of Baltimore, 2018). On a smaller scale, the city of Castlegar, British Columbia, undertook a study to understand how climate change could influence demands on the city's stormwater infrastructure (Kovacs *et al.*, 2014). Considering the changes underway in surrounding watersheds and climate projections, the study identified components of the city's stormwater infrastructure that were likely to be most vulnerable. A couple of years later, following heavy rain, the city decided to make investments in stormwater infrastructure improvements, and this study provided important support to decision-makers (Kovacs *et al.*, 2014).

2.4 Conclusion

Integrating DRR and adaptation presents its challenges: distinct governance mechanisms, terminology, and time scales all complicate progress. In addition, decision-makers are prone to maintain current practices, discount future risks, and postpone investments in future safety for a host of reasons. Notwithstanding these challenges, trends in climate change and disaster risks underscore the stakes involved and the corresponding importance of pursuing a wide range of measures to enhance resilience. Moreover, integrated responses are likely to be more efficient and effective, thereby stretching limited resources further. The next chapter describes key integrated actions that can reduce hazards, exposure, and vulnerability, and, ultimately, disaster risk.

3

Key Interventions for Building Disaster Resilience in a Changing Climate

3.1 Reducing Hazards

3.2 Reducing Exposure to Hazards

3.3 Reducing Vulnerability to Hazards

3.4 Conclusion

Chapter Findings

- Disaster risks can be reduced through actions that temper the hazard, lessen the exposure, and reduce the vulnerability of people and structures. Risks are best mitigated when communities and individuals collaborate to pursue a wide range of complementary actions. No one strategy offers a solution to all risks.
- Implementation of nature-based solutions is key to reducing disaster risk. Enhancing forest fuel management, developing green infrastructure in cities, and conserving ecosystems that buffer the effects of hazards all enhance resilience and offer numerous co-benefits for human and ecosystem health.
- Avoiding exposure to hazards will become increasingly necessary in a changing climate. Forward-looking zoning and land-use planning, as well as carefully constructed planned retreat strategies, offer solutions for minimizing the exposure of populations and infrastructure.
- Designing codes and standards so that structures and infrastructure systems can withstand future climate stresses is critical for ensuring the resilience of the built environment.
- Ensuring equitable access to temperature-controlled areas during extreme temperatures and building redundancies into critical infrastructure systems help to reduce social vulnerability to hazards.

There are a number of key opportunities for enhancing resilience through the integration of adaptation and DRR. Recognizing that risk is a function of hazard, exposure, and vulnerability, this chapter explores tangible actions that can be pursued by governments, organizations, businesses, and individuals to address each of these three components of risk. Many of the interventions considered are long-established components of DRR, but their potential contribution needs to be re-examined in light of climate change. The activities identified in this chapter are supported by adequate and accessible information (Chapter 4), appropriate funding (Chapter 5), and clear rules and accountabilities (Chapter 6).

3.1 Reducing Hazards

Some hazards, such as wildfires and heat waves, have the potential to be tempered by proactive interventions. Most notably, this includes fire prevention through fuel management, as well as reducing high temperatures in urban areas through urban greening.

Wildfire hazards can be effectively managed through a combination of mitigation measures and controlled burning

Wildfires can be mitigated through a variety of strategies, one of which is encouraging and incentivizing communities to take action to reduce their fire risk (Sankey, 2018). Small-scale activities, such as clearing away ground litter, removing dead or dying trees, pruning and thinning vegetation, and planting fire-resistant tree species, can all contribute to reducing the spread of wildfires (FireSmart Canada, 2018). Living firebreaks are another tool, where strips of fire-resistant trees and vegetation are planted on the outskirts of communities to prevent the spread of fires (Curran *et al.*, 2018). However, widespread implementation of these interventions is stymied by a lack of risk knowledge by property owners and is further hindered by the absence of regulatory enforcement of mitigation activities in most provinces (Lindsay, 2018; Tymstra *et al.*, 2020). Widespread communication initiatives such as the FireSmart program are necessary to inform and involve those living in the wildland–urban interface about the actions required to minimize their risks in these hazardous areas (Kovacs, 2018). Further discussion of social learning and community cohesion for wildfire preparedness can be found in Section 2.3.2.

Human-caused fires can be ignited through contact with broken power lines or along railways, especially during particularly dry and hot weather conditions. Vegetation growing along transmission corridors can interfere with power lines, and windstorms can further cause tree branches and other debris to damage or bring down power infrastructure (Feltmate *et al.*, 2020). These types of fires have led to lawsuits against utility providers, some of whom have been found criminally liable for fires sparked by their electrical lines (Oritz, 2019). One method of mitigating the fire risks created by damaged infrastructure is through pre-emptively cutting power to at-risk areas, effectively removing the ignition source even if lines are downed or damaged. California power provider San Diego Gas & Electric employs an in-house meteorology team to forecast fire danger and has built a network of weather stations to provide data across the service area (SDG&E, 2020). San Diego Gas & Electric considers current and historical weather conditions, a vegetation risk index, and information from first responders and other field observations to inform decisions around pre-emptive shut-offs (SDG&E, 2020). However, power shut-offs are not without controversy; shut-offs by Pacific Gas and Electric in 2019 were criticized for a lack of clear communication on the specific timing and locations where power would be unavailable, compounded by a website crash during some of the outages (St. John, 2019; Ho, 2020).

Courtesy of Parks Canada

Figure 3.1 Managing Vegetation with Fire, Pukaskwa National Park, Ontario

Another effective strategy for reducing wildfire hazards is to fight fire with fire by allowing more managed wildfire[5] onto the landscape to reduce the fuel load and promoting prescribed burns[6] and fuel management near human settlements and valuable infrastructure (Bowman *et al.*, 2020; Tymstra *et al.*, 2020). Studies have demonstrated that the frequency of wildfires can be reduced by the limited fuel load following a fire (Krawchuk *et al.*, 2006). Although managed wildfire and

5 Instead of being wholly suppressed, some wildfires can be carefully monitored and allowed to burn in order to reduce fuel loads, especially in areas where risk to human settlements is low.

6 Prescribed or controlled burning involves intentional fire-setting under controlled conditions to reduce fuel in fire-prone areas.

prescribed burning are recognized as effective and successful strategies for reducing wildfire impacts, implementation is not without risk. Weather conditions conducive to wildfire ignitions are becoming more severe, shrinking the window of opportunity for prescribed burning (Bowman *et al.*, 2020; Whitman, 2020). Additionally, losing control of prescribed fires can pose a significant threat to nearby communities and infrastructure (Whitman, 2020). Smoke pollution from large-scale prescribed burning initiatives can cause significant health impacts, including hospitalization and death (Bowman *et al.*, 2020). Many areas are also too densely populated to provide adequate space for fires to burn without abutting against communities or structures with value (Johnston & Flannigan, 2018).

Collaborations with Indigenous groups can be useful as a means of improving the uptake and use of managed fires (FireSmart Canada, 2020). Indigenous groups have expertise in cultural burning practices that have historically been ignored and inhibited by colonization and government regulations and legislation around fire suppression. First Nations, such as the Shackan Indian Band have successfully conducted cultural burns through collaboration with the First Nations' Emergency Services Society and the BC Wildfire Service (FireSmart BC, n.d.). Indigenous and Local Knowledge (ILK) has been used to decide when best to conduct burns throughout the year and to choose optimal locations for ensuring safe and successful burns. The application of such knowledge and its outcome acts as a positive example for revitalizing cultural burning in other First Nations communities in British Columbia (FNESS, 2021; FireSmart BC, n.d.). Recognizing Indigenous ways of knowing and expertise in fire management can reduce wildfire risk while offering other ecological and cultural benefits, such as supporting fisheries, reducing pests, improving berry patches, and encouraging the growth of medicinal plants (FireSmart Canada, 2020). In certain situations, this knowledge has been lost, but some Indigenous communities are bringing in experts from elsewhere to help return burning to the landscape (GVS, n.d.). Other fuel reduction practices, such as clearing brush and deadfall are actively being conducted by many Indigenous communities and have been successful in limiting fire extent in emergency situations (Christianson *et al.*, 2014; FireSmart Canada, 2020; PAGC, 2020). Fuel reduction programs offer benefits beyond risk reduction: "community members [are engaged] through the recruitment and training of local Indigenous fuel management crews, thereby providing economic benefits and career opportunities to families and communities, and potentially in other industries as well" (FireSmart Canada, 2020). Local support, collaboration, and capacity development can include the training and recruitment of Indigenous forestry professionals and resource managers, Indigenous wildfire managers, ILK liaisons, Indigenous equipment operators, and Indigenous wildfire firefighters (FireSmart Canada, 2020).

Urban greening can reduce extreme heat in cities

Increasing urbanization combined with climate change has resulted in increased exposure to heat extremes (Jia *et al.*, 2019). The construction and expansion of urban centres, and in particular the use of non-reflective and heat-absorbing construction materials paired with reduced vegetation, has resulted in increased temperatures (McKeown, 2015). High temperatures have been the cause of detrimental health effects and mortality, especially for socially vulnerable populations (McKeown, 2015). Careful design and construction of urban centres can mitigate extreme temperatures felt on the ground and within buildings (NRDC, 2012). Urban greening, which involves expanding tree coverage in cities, is one effective way of reducing the urban heat island effect[7] (Sanusi *et al.*, 2016). Tree canopy, in particular, can provide shade, lowering the ambient air temperature, as well as the temperature of asphalt, exterior walls, and rooftops (Glick, 2020). In recognition of these benefits, several Canadian cities have created tree-planting programs, including Hamilton, Kelowna, and London (ICF, 2018). Similarly, Toronto provides a number of community grants and incentives to promote the planting of trees on both private and public land (City of Toronto, 2021a, 2021b). Enhancing urban forests is a valuable strategy for adapting to climate change; however, the effects of climate change on trees themselves warrant consideration as well (Ordóñez & Duinker, 2014). Including urban forests in vulnerability assessments can ensure their significance in urban decision-making and increase the chances of success for addressing high temperatures in cities (Ordóñez & Duinker, 2014).

Green urban infrastructures provide a number of benefits, including moderating heat islands. Experiments have demonstrated that green rooftop temperatures are 30°C to 40°C lower than roof temperatures prior to green roof installation (Liu & Bass, 2005). Air temperatures above green roofs are also affected, measuring 4°C cooler than non-vegetated rooftops (U.S. DoE, 2004). If scaled up, green roofs could affect city-wide temperatures; modelling has found that if 50% of roofs in Toronto were vegetated, air temperatures would be reduced by 0.1°C to 0.8°C, and a further 2°C if roofs were irrigated (Liu & Bass, 2005).

3.2 Reducing Exposure to Hazards

Reducing exposure is integral to limiting the impacts of hazards on communities. Proactive and reactive strategies effectively minimize exposure and include measures such as effective land-use planning, planned retreat, and protective infrastructure.

7 The urban heat island effect is "a phenomenon where the impervious materials of urban construction absorb, store, and release heat energy" (Vargo *et al.*, 2016).

3.2.1 Proactive Strategies

Effective planning, zoning, and land use are key tools for keeping people and assets away from hazards

Controlling and limiting development in hazardous areas is important and depends on strong regulation and enforcement by municipal or regional governments to prevent construction and development (King *et al.*, 2016; AIDR, 2020). For example, the 2013 Calgary floods would have been much worse if the city had not already been avoiding floodway development by severely restricting new residential and business development in the 1-in-100-year floodway (Doberstein *et al.*, 2019). Strict new zoning laws in Toronto in the wake of 1954's Hurricane Hazel prevented development in riverine floodplains, resulting in minimal damage when rivers burst their banks during Hurricane Isabel in 2003 (Kelman, 2020). Beyond flooding, strict development laws can restrict or prohibit construction and expansion into the wildland–urban interface, providing local authorities with the power to severely limit exposure to fires in these zones (Kovacs, 2018).

In contrast, a lack of sufficient land-use planning and zoning can increase exposure to floods, as has been the case in Houston, Texas. The city's population has increased by 40% since 1990, and the resulting development has led to the widespread paving over of absorbent prairie ecosystems and increased development within floodplains (Shaw *et al.*, 2016; Kelman, 2020). Impermeable surfaces and changes to natural drainage have caused rainwater to exceed the capacity of existing bayous, urban drainage systems, and reservoirs, leading to the extensive and repeated flooding of many areas that were not previously considered at risk as they fall outside the 100-year floodplain. Even within the floodplain, increased development has been permitted despite the known risk (Shaw *et al.*, 2016). A lack of strict land-use planning and zoning has resulted in Houston experiencing more urban flooding than any other area in the United States in the last four decades (Shaw *et al.*, 2016).

Preventing development in hazardous zones can coincide with the protection and conservation of natural areas, thereby providing numerous co-benefits for the natural environment (IISD, 2021). As an example, wetlands can enhance resilience by providing a buffer from storm surges while removing contaminants and providing habitats for wildlife (Lempert *et al.*, 2018). Conservation initiatives contribute to the protection of ecosystem biodiversity, the enhancement of carbon sequestration, and the promotion of recreation and human health (IISD, 2021; Mitchell *et al.*, 2021). Preventing development in floodplains or on coasts can be achieved by declaring wetlands as protected spaces, as was done in New Brunswick in 2002 (Gov. of NB, 2002). The New Brunswick Wetlands Conservation Policy aims to conserve provincially significant wetlands, which include all coastal marshes (Gov. of NB, 2002). Coastal marshes stabilize shorelines, provide protection from flooding and storm surges, reduce erosion, enhance biodiversity, and provide recreational and cultural services (ICF, 2018). During Hurricane Sandy in 2012, coastal wetlands prevented an estimated US$625 million in flood damages (Narayan *et al.*, 2017). Coastal ecosystems might also be able to self-adjust in response to sea-level rise (Spalding *et al.*, 2014). Zoning in Toronto floodplains promoted the creation of multiple parks and green spaces, providing natural and recreational benefits to the population (Kelman, 2020). These types of initiatives are often categorized as nature-based solutions (NBSs)[8]; see Figure 3.2 for examples.

Forward-thinking land-use planning and zoning also contribute to the concept of sustainability. Indeed, "land use planning to reduce natural hazards is ultimately and fundamentally about promoting a more sustainable human settlement pattern and about living more lightly and sustainably on the earth" (Beatley, 1998). By promoting and pursuing sustainable land use, Canada works towards addressing select Sustainable Development Goals, particularly goals 13 and 15 (UN, 2015).[9]

Although avoidance approaches are largely successful at reducing exposure, they can sometimes be impractical or unachievable due to opposing but legitimate social pressures, such as urbanization and population growth, which increase the demand for land (King *et al.*, 2016). In addition, municipal governments responsible for zoning laws may have difficulty enforcing them due to a lack of resources and capacity or when faced with pressure from property developers to increase the expansion of communities (Burby, 1998). Furthermore, adaptive zoning depends on up-to-date and comprehensive hazard mapping, which can be expensive and takes time to develop (King *et al.*, 2016). In these types of situations, it is important to consider a suite of complementary risk mitigation options, including hard and soft defences, updated building codes, and building retrofits to improve the resilience of physical structures.

8 This report uses NBSs to refer to both naturally occurring systems (such as wetlands) and to approaches designed and constructed to mimic natural processes.

9 Sustainable Development Goal 13 is to "Take urgent action to combat climate change and its impacts" and Goal 15 is to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (UN, 2015).

Figure 3.2 Nature-based Solutions for Reducing Hazards and Exposure

Examples of nature-based climate solutions in Canada. Upper image: salt marsh and dune system protecting the coast of Prince Edward Island. Lower image: green roof on the Vancouver Convention Centre, British Columbia.

3.2.2 Reactive Strategies

Planned retreat can play an important role in relocating people and assets away from areas that are most exposed to hazards

Once infrastructure and populations are settled in hazardous areas, reducing exposure becomes much more difficult and expensive (King *et al.*, 2016; AIDR, 2020). The policy option of planned retreat (also known as managed retreat), primarily implemented through the process of government buy-outs of homes and buildings in high-risk flooding areas, can be effective at reducing exposure (Thistlethwaite *et al.*, 2020). In Australia, devastating wildfires in 2009 prompted the State of Victoria to buy back more than 100 destroyed properties and require special permits for new buildings in high-risk areas (Slezak, 2013). One of the most often-cited examples of a successful planned retreat in Canada occurred in the aftermath of Hurricane Hazel, where the Government of Ontario purchased over 200 homes and properties damaged during the flooding in Toronto (Thistlethwaite *et al.*, 2020). Flooded areas were converted into greenspace that persists to this day (Kelman, 2020). The retreat and subsequent rezoning strategy employed in floodplains throughout the Greater Toronto Area has significantly reduced the flood risk; however, the Toronto and Region Conservation Authority estimates that at least 8,000 properties are still at considerable risk from flooding, and further retreat may be required to manage flooding in a changing climate (Doberstein *et al.*, 2019; TRCA, n.d.).

The design of any planned retreat program requires careful consideration in terms of timing, compensation, and where communities can best be relocated. Programs that are designed to engage meaningfully with stakeholders in advance of a disaster have greater success in convincing communities to consider planned retreat (Binder & Greer, 2016). Conversations about planned retreat in the immediate aftermath of a disaster are not appropriate; it is an emotionally fraught period in people's lives, as their homes and livelihoods have been destroyed or damaged (Flavelle, 2020; Tait, 2020; Thistlethwaite *et al.*, 2020). Planned retreat is often viewed as a last resort akin to defeat or failure and is resisted for those and many other reasons, including high upfront costs, people's connection to place, and the loss of culture and community (Binder *et al.*, 2015; Flavelle, 2020).

Indigenous Peoples may be especially wary of retreat due to the colonial legacy of stolen land and the relocation of communities against their will (Yellow Old Woman-Munro *et al.*, 2021). Therefore, public dialogues about planned retreat options are recommended to gain public support and design a program that will suit the needs of the community (Binder & Greer, 2016). Should planned retreat be a viable option for a community, it is crucial to consider where these displaced populations would resettle in advance of potential disasters to protect the ongoing health of those affected (Saunders-Hastings *et al.*, 2020) (Box 3.1).

Adequate compensation is an equally important consideration for planned retreat to succeed. In the wake of Hurricane Sandy, at one community-led meeting on Staten Island, almost all residents indicated they would be interested in leaving if they could secure a fair price for their homes and a guarantee that the area would not be redeveloped (Meyer & Kunreuther, 2017). Following the flooding of the Mississippi River in 1993, various counties in Iowa designed programs for buy-outs of at-risk properties; the counties of Cherokee and Ames relocated populations into safer parts of the city and created green space buffers to act as floodplains (Siders, 2013). These programs were deemed to have successful results because the residents were offered pre-flood market values for their homes, with additional incentives if residents relocated within the city (Siders, 2013). In contrast, the Government of Quebec offered to buy out flood-damaged homes at a cap of $200,000 in 2019, causing backlash and resistance, as homeowners perceived their homes to be worth more than was offered and because the offer would not allow them to purchase equivalent homes elsewhere in the area (Breummer, 2019; Thistlethwaite *et al.*, 2020).

Box 3.1 The Relocation of Lake St. Martin First Nation

The ongoing displacement of the Lake St. Martin First Nation serves to emphasize the importance of culturally appropriate and respectful plans for both evacuation and relocation. In 2011, flooding destroyed all housing and infrastructure and forced the evacuation and displacement of the Lake St. Martin First Nation in Manitoba (Ballard & Thompson, 2013). Their traditional lands were flooded as a result of the decision to divert excess water away from Lake Winnipeg and into Lake St. Martin, which prioritized property owners and farmers along the Fairford River and Lake Manitoba (Galloway, 2012). This decision was out of the hands of the First Nation, which was further ignored when the time came to choose a relocation site; the site the Nation requested was not selected, and instead a remote parcel of land adjacent to the original, flooded-out reserve was chosen, even though it held similar risk of flooding (Galloway, 2012; Thompson *et al*., 2014). Nine years later, some residents had still not been able to return to their homes, and a lawsuit was launched against the federal government for stopping evacuee benefits before providing safe and secure housing (Malone, 2020; Unger, 2020). Thompson *et al*. (2014) summarize the situation:

> *Institutional and policy barriers, stemming from jurisdictional issues, as well as racism, [have] interfered with needed services and joint decision-making on water management and land for their new community. Policies regarding water management, post-evacuation services, and community redevelopment have not provided a voice for [First Nations] to ensure their needs are met in a respectful and culturally appropriate way. In partnership with [First Nations], inclusive policies and procedures must be developed to prevent and mitigate future impacts of natural disasters and displacement.*

This experience highlights the negative consequences that can arise when relocation is poorly executed.

The Hamlet of Tuktoyaktuk in Northwest Territories is actively incorporating planned retreat into their adaptation strategy to accommodate the coastal erosion and permafrost degradation that is threatening physical infrastructure and the economic and physical health of the community (Andrachuk & Smit, 2012; Saunders-Hastings *et al.*, 2020). Although the local community has been a leader in relocation discussions from the outset, persistent challenges related to funding and a lack of technical expertise in the community have been barriers to finding suitable relocation areas and the implementation of retreat (Saunders-Hastings *et al.*, 2020). This underscores the need for financial and technical support from the territorial and federal governments to make progress on the next phases of the retreat strategy.

Built and natural protective infrastructure can reduce exposure at the community level

In many situations where planned retreat is not a feasible strategy, reducing exposure through protective strategies becomes critical. For example, protecting populations and physical infrastructure from coastal and riverine flooding has traditionally involved the use of hard infrastructure such as sea walls, dikes, levees, and berms. Communities in British Columbia's Lower Mainland are protected from flooding by a system of more than 600 kilometres of dikes, which have been essential in preventing damage to critical infrastructure, housing, and several hundred thousand inhabitants (Gov. of BC, n.d.-b). Such dikes, however, are increasingly vulnerable to failure due to climate change, which is introducing new stresses to infrastructure that may not be accounted for in existing design practices (IPCC, 2012; SCC, 2019b). In the Fraser River Delta, 71% of dikes were determined to be vulnerable to overtopping, and if no changes are made to the current system, future damage estimates range from $24 billion for coastal flooding to $32 billion for riverine flooding (FBC, 2016). One way to improve flood protection infrastructure is to make sure it can be resized during subsequent infrastructure replacement and renewal cycles (Moudrak & Feltmate, 2020). In the Netherlands, dikes have been raised to accommodate the most likely amounts of sea-level rise; however, if seas rise higher than expected, the foundations of these dikes are strong enough to accommodate extra height (Hill & Martinez-Diaz, 2020). Ensuring that building codes and standards are updated to reflect expected future climate conditions is another way to promote continuous improvement of structures when being repaired and retrofitted (Hill & Martinez-Diaz, 2020).

The rejuvenation of natural wetlands, floodplains, beaches, and coasts offers an alternative solution to traditional hard barriers, such as sea walls and dikes. NBSs are increasingly being recognized for their potential to reduce exposure to the impacts of climate change while also supporting other co-benefits (OECD, 2020a; Stafford *et al.*, 2021) (Section 3.2.1). Some NBSs are also examples of safe-to-fail systems; green spaces along rivers can safely flood in the event of heavy rainfall, resulting in minimal repairs (Wharton, 2015). In some other situations, hybrid grey–green[10] approaches offer the best solutions. For example, fortified dunes feature natural sands and grasses combined with riprap rock to help prevent erosion and flooding (ICF, 2018). Offshore protections such as barrier islands can also be maintained and used to complement structures such as dikes and have been suggested for parts of the Vancouver area (Delcan, 2012). Dikes are being installed near Sackville, New Brunswick, while the Tantramar salt marshes are being restored simultaneously (Molnar *et al.*, 2021). This fusion of strategies can help to increase the resilience of both natural systems and traditional infrastructure to more severe events and garner increased support from professional communities more familiar with engineered approaches (ICF, 2018).

Protective infrastructure should be used with caution, however. When these defensive structures are in place, they can instill a false sense of security in populations protected by them (Kelman, 2020). Believing themselves to be immune to hazards, residents may become complacent and not take actions to manage vulnerability. Instead of solely relying on one type of risk mitigation — in this case, protection — communities and individuals need to actively pursue diverse and complementary avenues, such as flood-proofing homes, owning insurance, and updating emergency plans (Doberstein *et al.*, 2019; Kelman, 2020).

3.3 Reducing Vulnerability to Hazards

The concept of vulnerability has been studied and defined in many different ways by a wide variety of professions and disciplines with a long history of research in disaster studies (Hewitt, 1983; Blaikie *et al.*, 1994; Cutter, 1996). For this report, the Panel has chosen to keep to the United Nations Office for Disaster Risk Reduction (UNDRR, 2016) definition provided in Box 1.1 and to consider susceptibility and lack of capacity as components of vulnerability. Vulnerability is comprised of many dimensions, including physical (referring to buildings and infrastructure), social, economic, cultural, and environmental, and it is important to recognize that vulnerability is both created and reduced through human choices (Birkmann *et al.*, 2013; Kelman, 2020). When considering the integration of adaptation and DRR, the majority of interventions address physical or social vulnerabilities.

10 Grey infrastructure refers to conventional structural approaches (often including grey materials such as concrete).

3.3.1 Physical Vulnerability

Disasters damage individual homes and buildings; large-scale community infrastructure, such as roads and power lines; and the very structures designed to defend against hazards, such as dikes, berms, and dams. Physical vulnerability is increased through poor building and infrastructure design, lax regulation, and codes and standards that do not consider the changing climate. Addressing physical vulnerability is one of the key places where adaptation can be integrated with DRR.

Codes and standards that integrate future climate change can significantly enhance the resilience of new structures

Codes and standards have a significant impact on all phases of building and infrastructure life cycles and are therefore a crucial entry point for the incorporation of adaptation. Traditionally, infrastructure standards are built upon historical estimates of a relatively stable climate; however, climate change is rendering these assumptions invalid (SCC, 2019b). Outdated infrastructure design standards contribute to a diminished capacity to manage risk, especially flooding (Thistlethwaite & Henstra, 2017). By incorporating projections for future climate conditions, codes and standards increase the resilience of new physical structures and reduce the need for costly future retrofits (Section 5.2.1). Ongoing maintenance of structures can also extend their expected service life (SCC & Manifest Climate, 2021). The value of climate-adjusted codes and standards is well-recognized through ongoing funding; the 2021 federal budget committed $11.7 million over five years to support the renewal of the Standards to Support Resilience in Infrastructure Program (GC, 2021c). Standards and building codes are most effective when paired with strong enforcement and training (Eyzaguirre *et al.*, 2018).

Work is already underway to develop standards that address existing and anticipated climate-related hazards for a variety of building and infrastructure types. The Northern Infrastructure Standardization Initiative supports geotechnical site investigations for building foundations in permafrost regions while accounting for future climate conditions (SCC, 2018). Other similar standards can be developed to address increased infrastructure vulnerability to climate change across Canada. A national standard for managing stormwater systems is under development by the Standards Council of Canada (SCC, 2019b), and the Bureau de normalisation du Québec has issued standards relating to reducing heat islands in populated areas (BNQ, 2013; SCC, 2019b). A national standard for flood resilience has been suggested by Moudrak and Feltmate (2017) to help municipalities, homeowners, builders, and developers comprehend the expected design and construction requirements for more flood-resistant infrastructure.

Further development and revision of standards can be aided by guidelines created by the International Organization for Standardization, which provides a methodology for standards committees and developers to integrate climate change (ISO, 2020). The Standards Council of Canada has also released a document to guide the integration of adaptation into standards that are currently under development or revision (SCC & Manifest Climate, 2021). This guidance provides a step-by-step process for activities such as gathering relevant climate data, defining the climatic conditions that will likely affect the standard, assessing climate impacts for each life cycle stage, and completing climate risk assessments (SCC & Manifest Climate, 2021). Beyond accounting for climate change, codes and standards can additionally improve resilience by promoting equity (RNPN *et al.*, 2021). The Standards Council of Canada has recognized this and has developed a strategy to incorporate the principles of Gender-based Analysis Plus (GBA+) into standards development (SCC, 2019a).

Many construction and maintenance strategies can reduce vulnerability at the property level

At the scale of individual homes, activities such as clearing gutters of debris, extending downspouts and sump pump discharge pipes, installing and maintaining backwater valves, and landscaping to maintain a positive grade all contribute to lessening physical vulnerability to floods (Moudrak & Feltmate, 2020). Buildings are more resilient when they use materials capable of withstanding prolonged contact with flood waters, and the use of landscaping features such as green roofs, vegetated channels (bioswales), and rain gardens can further contain stormwater and minimize runoff (Moudrak & Feltmate, 2020). To minimize vulnerability to wildfires, property owners can ensure that roofs and siding are well rated for fire resistance, vents are constructed of non-combustible materials, and windows are tempered (FireSmart Canada, 2018). Installation of inexpensive roof clips (also known as hurricane ties) has been recommended for reducing the risk of roof damage during high wind speeds, such as those experienced in Dufferin County during tornados (Darwish, 2018).

Large commercial and residential towers are also at risk from hazards but can be built and retrofitted to reduce vulnerability to hazards such as flooding or heat waves. For example, backup generators can be onsite at all times to provide power to at least one elevator, as well as sump pumps and fire alarm systems (Moudrak & Feltmate, 2020). Elevators can also be equipped with water sensors to prevent them from travelling to flooded floors (Moudrak & Feltmate, 2020). The implementation of these strategies depends on sufficient awareness of risk and of options available for mitigating it. Financial supports and incentives can also increase the uptake of these solutions, such as through subsidies or insurance (MPA, 2019).

Community-level infrastructure improvements are key to reducing vulnerability

At community or city scales, emphasis is on improving the resilience of existing infrastructure and avoiding exacerbating existing vulnerabilities through new construction. Significant portions of Canada's infrastructure are in poor or very poor condition, requiring either immediate or near-term replacement and repair (CIRC, 2019). Urban drainage systems are under increasing stress due to severe rainfall events (CIRC, 2019; Moudrak & Feltmate, 2019). Recommendations to reduce the risk of flooding include ensuring that stormwater and sanitation sewers are fully separated, keeping maintenance hole covers away from low-lying areas, and disconnecting discharges from downspouts and sump pumps from sanitary sewers (Moudrak & Feltmate, 2020). To reduce the risk of wildfires and to prevent power outages, some utility companies are exploring hardening their transmission systems through the use of covered conductors, falling conductor protection, enhanced vegetation management, and shifting some lines underground (SDG&E, 2020).

> "Existing vulnerabilities are exacerbated and compounded by disasters and climate change."

These conventional approaches can be complemented by green infrastructure as well. Green roofs, permeable pavement, and rainwater harvesting can all reduce stormwater runoff (TRCA, 2010). Green approaches can also be less expensive than conventional grey structures. For example, permeable, green surfaces on streets and alleyways in Portland, Oregon, have been estimated to be three to six times more cost effective for stormwater management than alternative infrastructure options (Foster *et al.*, 2011). In that case, US$8 million in green infrastructure investments such as permeable street surfaces and rain barrels have saved an estimated US$250 million in avoided hard infrastructure costs (Foster *et al.*, 2011).

3.3.2 Social Vulnerability

Social vulnerability encompasses characteristics of individuals, including health, age, and gender, as well as societal aspects, including demography, economics, and cultural norms (Kelman, 2020). Existing vulnerabilities are exacerbated and compounded by disasters and climate change. For example, persons with mental or physical disabilities have extended recovery times following a disaster, and they may lack sufficient resources to adequately address their everyday needs and to adapt and be resilient to climate change (Etkin, 2010; Gaskin *et al.*, 2017).

The key interventions needed to address social vulnerability are generic and include measures such as strong social safety nets, access to health services, and community cohesion. Progress on improving these measures in the short term will additionally work towards enhancing resilience to hazards in the future (Kelman *et al.*, 2017). Furthermore, adaptation and DRR initiatives should complement existing efforts to address social inequity and reduce vulnerability (Brown *et al.*, 2021). Ensuring that those most vulnerable to climate-related hazards are provided with the opportunity to participate in knowledge generation and decision-making is a critical aspect of improving resilience (Section 6.1). For the most part, broad interventions to address social vulnerability are beyond the scope of this assessment, but the Panel identified a few targeted actions.

Public access to cooled areas can save lives during extreme heat events

Heat waves are projected to increase in the future and have also occurred frequently in previous years. Winnipeg, Ottawa, Halifax, Toronto, Vancouver, and Montréal have all been affected, with significant death tolls as a result (PCC, 2019). Heat waves pose particularly high risks to vulnerable populations such as the elderly, those experiencing homelessness, individuals with mobility issues, the socially isolated, or those with impaired health (HC, 2011; Watts *et al.*, 2015; PCC, 2019). In areas with significant wildfire activity, poor air quality due to smoke combined with extreme heat results in especially dangerous conditions for vulnerable populations who often have to choose between experiencing high indoor temperatures and difficulty breathing outdoors (Ball, 2021). In Toronto, locations with high vulnerability to heat stress coincide with clusters of apartment buildings constructed prior to 1986 (McKeown, 2015). These buildings largely lack air conditioning for individual units, making their residents increasingly vulnerable as climate change and the urban heat island effects intensify. Proposed solutions include installing insulating blinds, adding grates to existing windows to allow them to open wider, coating roofs with reflective material, and conducting major retrofits, such as adding new roof and wall insulation, installing cladding, and replacing windows with more energy-efficient models (McKeown, 2015).

Furthermore, cooling centres within buildings have been recommended to provide space for occupants to escape the heat (McKeown, 2015). The provision of cooled areas has been shown to significantly reduce mortality to heat waves; in 1999, the City of Chicago proactively opened cooling centres and issued a heat warning, resulting in a mortality rate drop of over 80% in comparison to an earlier heat wave in 1995 (Palecki *et al.*, 2001). Some of these proposed solutions are considered to be "deep retrofits" and have largely been passed over due to their extremely high costs (MPA, 2019). Policy changes and access to funding can help to encourage these actions, which in turn can produce co-benefits, such as reduced water and energy usage (MPA, 2019).

In addition, both hot and cold temperature extremes have significant impacts on homeless communities. Many regions provide specialized cold-weather supports; however, there is also a need to extend these programs to account for heat waves (Hazlewood, 2020). Public spaces with air conditioning are vital and can be supplemented with widespread cooling centres to specifically provide this service (Moon & Wallace, 2018). The City of Vancouver has recognized the importance of providing cooler areas for especially vulnerable populations, such as in the Downtown Eastside, and is planning on implementing increased tree cover in addition to opening air-conditioned community centres during heat waves (VBPR, 2019). If successful, this approach could be expanded to other locations to create a cooling network in tandem with increased tree planting (McKeown, 2015).

Building redundancies into supply chains and infrastructure systems can minimize service outages and reduce the vulnerability of isolated communities

Many natural hazards have the potential to damage critical infrastructure, such as power generation, potable water, and wastewater systems. Decentralizing these systems and building in redundancies can reduce catastrophic impacts on populations. The City of Vancouver has proposed the use of green water infrastructure[11] to support seismic resilience in particular, though the same lessons apply to climate change-affected hazards such as floods and fires (City of Vancouver, 2019). By decentralizing drainage systems, a single point of failure will not affect the entire system (City of Vancouver, 2019). In 2021, storms in Texas highlighted the vulnerability of a largely unconnected power system when the state was unable to bring in electricity from other parts of the country due to the lack of interconnectedness (Meyer, 2021).

11 A mix of engineered and ecosystem-based practices for the protection and restoration of the natural water system, including the harvest and reuse of rainwater.

Northern and remote communities are especially vulnerable to disruptions or failures in critical infrastructure and transportation networks, as climate change affects permafrost, snowfall, and snowmelt (Vodden & Cunsolo, 2021). Shifting ground due to permafrost thaw has been increasingly destabilizing building foundations and causing high maintenance costs for linear structures such as roads, railways, and airport runways (GRID-Arendal, 2020). In remote regions, the provision of essential services is much more difficult, and a lack of reliable access, in turn, can exacerbate existing vulnerabilities. For example, in 2017, the only railway line connecting the remote town of Churchill to southern Manitoba was washed out and damaged in several places due to intense spring flooding (MacLean, 2017; Malone, 2018). Although the flooding did not affect the town directly, it had a huge impact on the livelihoods and health of the residents of Churchill. This rail line was the only way that fuel and food were being brought to the town, and Churchill itself further acted as a distribution centre for other communities in the North (Galloway, 2018; Hansen, 2018). In the aftermath, commodities had to be brought in by sea or air at hugely inflated prices, driving many residents to move away (Malone, 2018). The economy of Churchill was additionally affected through the cessation of tourism, which many residents depended on for their livelihoods (Malone, 2018). Although the railway has since been repaired, it remains vulnerable to climate change, as large portions of it sit on permafrost, which is thawing at increased rates (MacLean, 2017). These types of critical supply chain disruptions further exacerbate the existing food insecurity experienced by many Indigenous communities in the North; affordable and nutritious market foods are already lacking due to the cost of transport, and the range and distribution of country foods are being affected by climate change (ITK, 2019).

The issue of access is common to many remote and northern communities. In the event of a disaster, a community's ability to receive aid or evacuate is drastically reduced when there are no built-in redundancies. Potential solutions to these problems include altering transportation routes, updating infrastructure, modifying seasonal shipping times, and connecting communities to a central grid (Vodden & Cunsolo, 2021). However, implementing these actions is expensive, and communities may not have the resources to enact them. Support from FPT governments in the form of regionally relevant climate information, technical expertise, and funding is therefore critical to address limited local government capacity (Vodden & Cunsolo, 2021).

3.4 Conclusion

At the individual, neighbourhood, community, city, or regional scale, the interventions identified in this chapter work to lessen hazard, exposure, and vulnerability in a changing climate. These approaches do not exist in a vacuum; they are rooted in up-to-date, relevant, and accessible information, adequate funding, and comprehensive insurance policies. Decision-makers at all jurisdictions need to coordinate their actions, with FPT governments supporting and recognizing the capabilities of municipal and Indigenous governments. Ensuring that those most affected by climate change and disasters have a voice at the table is critical to fostering whole-of-society resilience, as is recognizing the role that private institutions, planners, researchers, non-governmental organizations (NGOs), and others play.

Figure 3.3 illustrates the relationships among all of these aspects, showing how the different elements of the report connect. Effective DRR and adaptation both depend on (i) information that is available, accessible, and applicable to a range of decision-making contexts, and (ii) funding, investment, and insurance programs and policies that motivate the appropriate actions. Appropriate governance structures are then called for to integrate DRR and adaptation, including whole-of-society, bottom-up processes alongside top-down government mandates. All of these elements come together to bring about the range of actions described throughout this chapter to reduce hazards, exposure, and vulnerability in a changing climate.

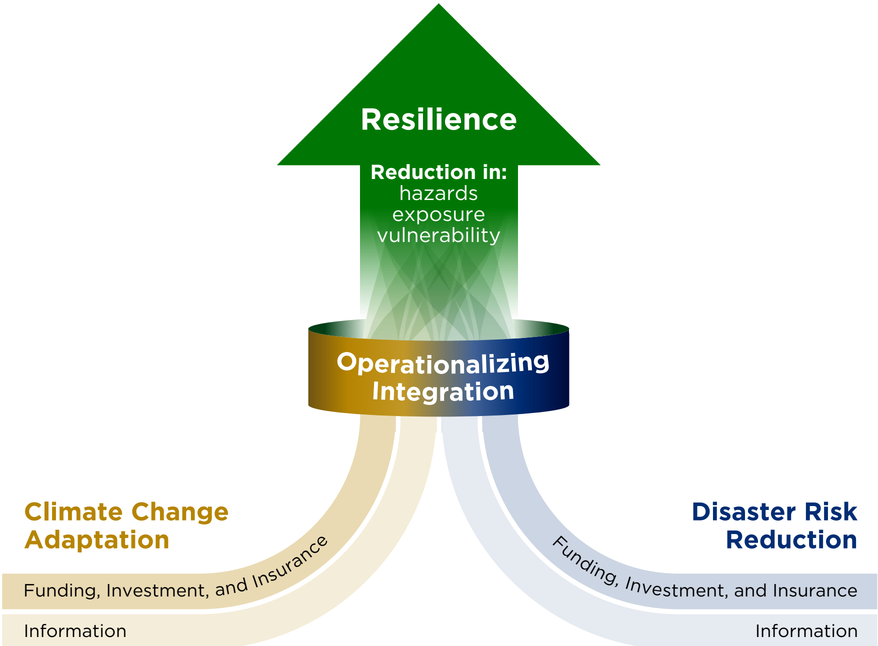


Figure 3.3 Conceptual Framework for Improving Disaster Resilience Through the Integration of DRR and Adaptation

There is an opportunity to enhance disaster resilience through the integration of DRR and adaptation. In particular, information resources, funding programs, investment choices, and insurance offerings that factor in climate change alongside other DRR considerations will contribute to more effective decision-making. Integration requires systems to operationalize these tools and interventions through whole-of-society engagement, local leadership, and well-enforced legislation.

4

Information for Disaster Resilience Decision-Making

4.1 Existing Barriers and Incentives

4.2 Promising Approaches

4.3 Capabilities

4.4 Key Opportunities for Integration

Chapter Findings

- A variety of well-developed climate models, web portals, and climate services are available to inform appropriate decision-making. Some degree of uncertainty in this information is inevitable; however, that is not an adequate reason for deferring action on climate-adapted decision-making.
- Improving the quality and availability of climate and disaster data is important. In particular, localized, high-resolution data that is applicable to specific decision contexts is largely absent, and the understanding of extremes is relatively weak.
- The Canadian Disaster Database is insufficient as a national resource for DRR and adaptation practitioners. In order to better serve these communities, data regarding exposure and vulnerability to climate hazards as well as impacts must be up-to-date, consistent, and comprehensive.
- Recognizing the value of ILK and actively engaging with Indigenous knowledge holders is critical in the effective reduction of risk. Indigenous knowledge holders contribute to resilience through their understanding of local risk and community strengths.
- Knowledge brokers, such as regional climate services and consultants, are critical in ensuring that information is effectively communicated and applied to analysis in ways that are most useful for decision-makers. Enabling a meaningful, two-way relationship between information providers and users is required for the effective integration of DRR and adaptation.

When it comes to understanding disaster risks in a changing climate, decision-makers need information about hazards, exposure, and vulnerability. Information types vary and include historical data, trends, and projections, and they encompass economic, demographic, social, environmental, and physical dimensions (Eyzaguirre *et al.*, 2018). This information must be packaged in ways that prove useful, and decision-makers must learn to make the most of the available information resources. Users of climate information are diverse, with variable expertise, needs, and levels of trust (Bauer & Smith, 2015). These users include journalists, farmers, policy-makers, engineers, business executives, planners, community organizations, investors, and many others (Bauer & Smith, 2015; Engineers Canada, 2019).

Information is an essential component of risk-aware behaviour and decision-making in both DRR and adaptation (IPCC, 2012; Eyzaguirre *et al.*, 2018). Without the integration of information resources, efforts to advance adaptation and DRR can be ineffective. When planning and development controls hinge on historically based floodplain mapping, it allows for assets to be built in places that will be increasingly exposed to hazards in a changing climate (Thistlethwaite & Henstra, 2017). Similarly, climate change is altering the operating environments for infrastructure and has the potential to be ignored when designs are based on historical climate ranges alone (Swiss Re & GIF, 2021). Equally, integrated risk assessments, which combine multiple approaches and sources in a consistent and organized manner, are essential for guiding investments in resilience (TBS, 2016). At the strategic level, DRR and adaptation are both informed by the outputs of risk assessments, and their integration can be enhanced by explicitly including climate change in assessments of disaster risks (EEA, 2017; Eyzaguirre *et al.*, 2018).

This chapter explores barriers to the integration of DRR and adaptation due to the availability, accessibility, and applicability of information and identifies promising approaches to enhancing integration. It concludes by identifying some of the key capabilities that could be further developed to enhance the use of information in fostering disaster resilience.

4.1 Existing Barriers and Incentives

It is not sufficient for information to exist; it also needs to be accessible and presented in ways that are conducive to informing choices. This section outlines the impediments of availability, accessibility, and applicability, clarifying the barriers that currently inhibit greater reliance on information for decision-making.

4.1.1 Availability of Information

Fundamental uncertainties limit the nature and reliability of some kinds of information

There are significant gaps in historical data on disasters and climatic conditions, and while additional research can provide greater insights into the past, some fundamental uncertainties will remain. Gaps in weather data persist, particularly in relation to extreme values (ECO, 2018). Datasets describing climate extremes are limited, even in many non-remote, southern regions of Canada where, for example, extreme rainfall records are lacking. There have been significant changes in Canada's official climate data networks since the 1990s, with a general decline in the number of data stations and an increase in the amount of missing data from the remaining observation stations (ECO, 2018). Quality control of archived climate data also creates challenges owing to factors such as automated gauges, measurement difficulties brought on by wind speed, and variability across measurement devices (Goodison *et al.*, 1998; Mekis *et al.*, 2018). These challenges can impact the design of future Canadian infrastructure assets since codes and standards may be compromised if the data available on extreme events is insufficient (BCMOTI *et al.*, 2014b).

Shifting climate conditions and the corresponding impacts are subject to high levels of uncertainty, which limit the nature and reliability of the information available to decision-makers. This uncertainty stems from variability in the natural climate, unknown future emission trajectories, and model uncertainties (Cannon *et al.*, 2020; Fiedler *et al.*, 2021). The ability of climate models to provide insights into relatively rare and extreme events remains inadequate due in large part to a lack of long-term observations and model simulations (Fiedler *et al.*, 2021). Other factors further heighten uncertainty, including long time horizons, the variability of climate impacts across locations, the inherent complexity of the climate system, and the interconnectedness of climate change consequences (U.S. National Research Council, 2009). In this context, decision-making becomes more complex, and historical best practices become obsolete (Roy *et al.*, 2017). Lemos and Rood (2010) identify an uncertainty fallacy, which they define as "a belief that the systematic reduction of uncertainty in climate projections is required in order for the projections to be used by decision makers." In this context, uncertainty can be misused to justify postponing action.

Key knowledge gaps include hazard maps, downscaled climate projections, disaster data, the performance of nature-based solutions, economic analysis, and risk assessment

As practitioners work to devise strategies for enhancing resilience, they encounter significant barriers to accurately understanding the risk landscape. This in turn hinders their ability to effectively analyze strategies to address these risks. Flood maps are one prominent example of an important information deficit; in Canada, these maps are often out of date, reflecting past climate conditions and land uses (Sandink *et al.*, 2010; Parsons & BCREA, 2015). A lack of information on whether a property has previously been flooded or qualified for an insurance claim, as well as out-of-date floodplain maps, contribute to a lack of understanding of flood risk in many regions (Conservation Ontario, 2013; Noël, 2013; Thistlethwaite & Henstra, 2017). Furthermore, incentives to update floodplain maps are limited since structures built in a location recognized or zoned as a flood risk area prior to construction are ineligible for relief under the federal Disaster Financial Assistance Arrangements program (PS, 2007). A lack of high-quality flood mapping was identified by the insurance industry as a barrier to offering flood insurance, and the completion of flood maps was included in the 2019 mandate letters to the Federal Ministers of Environment and Climate Change and of Natural Resources (Sandink *et al.*, 2010; PMO, 2019b, 2019c).

Although climate data created by general circulation models are widely accessible, they often exist at too coarse a spatial resolution (on the order of hundreds of kilometres) to be beneficial to practitioners at the local or community level (Wang, 2016; Cannon *et al.*, 2020). A lack of downscaled climate projections, which reflect higher-resolution data and smaller geographic scales, can impede efforts to incorporate future climate projections into DRR (Birkmann & von Teichman, 2010). Fiedler *et al.* (2021) argue that "[c]alls for the integration of climate science into risk disclosure and decision-making across many levels of economic activity [have] leap-frogged the current capabilities of climate science and climate models by at least a decade." Furthermore, there is a lack of information regarding the severity of and trends in disasters worldwide. For example, Bowman (2018) notes how little certainty exists in the realm of wildfire trends; the lack of a global database for mapping and monitoring fires severely constrains the ability of researchers and practitioners to understand wildfire severity and trends. The Panel notes that although there has been much investment in improving the availability and accuracy of climate data, some degree of uncertainty is inevitable. This uncertainty, however, ought not to stand in the way of decision-making, as much of the existing information can be effectively and appropriately utilized. What remains missing, however, is information at a high enough resolution to help decision-makers in specific, localized contexts. This challenge is exacerbated by the rarity of extreme events (Fiedler *et al.*, 2021).

> "This uncertainty, however, ought not to stand in the way of decision-making, as much of the existing information can be effectively and appropriately utilized."

The nation's main source of historical data on disasters, the Canadian Disaster Database (CDD), also suffers from severe limitations. The CDD is populated using a wide range of data sources, resulting in variable data reliability (King-Scobie, 2019). The ability to conduct comparative analyses using CDD data is impaired by "differences in jurisdictional responsibilities, the type of data that is available, and how it is collected and used over time" (PS, 2019a). The use of a single entry for each disaster fails to provide information at the community level (King-Scobie, 2019). Furthermore, cost and loss data presented in the CDD are not reported consistently, and it may take many years before they are finalized (PS, 2019a). Finally, data are not always updated in a timely manner nor is the database comprehensive (PS, 2019a). The Government of Canada's *Policy on Service and Digital* and the Treasury Board Secretariat's (TBS) *Standard on Geospatial Data* highlight the deficiencies in the CDD's data, as they both emphasize the need for interoperability in data sets (TBS, 2012, 2020). The *Policy on Service and Digital* outlines responsibilities associated with the open and strategic management of information, including the establishment of program-wide information and data standards and the promotion of data management that enables interoperability, analysis, and decision-making (TBS, 2020). The Panel notes that these deficiencies could be overcome by placing higher priority on keeping the CDD up-to-date with as much detail as possible, as well as by establishing reporting guidelines. By ensuring that the information is timely, comprehensive, accurate, and comparable, the CDD can become a valuable asset in the effective integration of DRR and adaptation.

Performance data is also lacking for NBSs, which can be subject to large uncertainties in terms of the time scale, nature of benefits, and their efficacy under climate change and extreme events (ECCC, 2020a). NBSs are generally deployed in an ad hoc manner, resulting in sparse and case-specific performance data that may be collected inconsistently and at a variety of time scales (Bush & Doyon, 2019; OECD, 2020a). This uncertainty can deter their further use and leads decision-makers, planners, and engineers to favour traditional grey infrastructure due to its familiarity in terms of compliance and permitting (OECD, 2020a). Research has been undertaken within the last decade to find innovative solutions for harnessing the benefits of existing ecosystems and investing in green infrastructure that mimics natural functions in a way that attempts to limit the possibilities of maladaptation, although large-scale deployment has not yet been achieved (Glick, 2020).

More broadly, a lack of economic analysis that offers clarity on the relative costs and benefits of adaptation investments compromises the efficiency of decisions (Arent *et al.*, 2014; Eyzaguirre & Warren, 2014; CCA, 2019b; Sawyer, 2020). While it is generally recognized that the costs of inaction often exceed those of proactive adaptation measures (e.g., NRTEE, 2011; Lempert *et al.*, 2018), the information needed to establish a business case for adaptation investments is often unavailable. The benefits of these investments in adaptation are not immediately apparent since they are the savings associated with the avoidance of a negative outcome that did not come to pass. As a result, it can be tempting to prioritize investments that produce short-term, tangible benefits (Roy *et al.*, 2017).

4.1.2 Accessibility of Information

Decision-makers are not always aware of or have access to existing information

The 2007 *Emergency Management Act* obliges PS to prepare emergency management plans for all identified risks (GC, 2007). A national All-Hazards Risk Assessment (AHRA) is one mode through which this information is gathered. According to PS (2012), "the AHRA process is meant to create a multi-dimensional, high-level view of risks faced by Canadians, while bringing diverse risks from various sources into the same high-level view." While the methodology for conducting the AHRA has been made public, Canadians currently lack access to the national risk assessment on national security grounds (OECD, 2017a). Accordingly, the distribution of Canada's AHRA is limited to senior federal officials responsible for emergency management. The lack of an accessible AHRA is problematic and puts Canada in a weak position relative to many other OECD countries. For example, in Norway, the public accessibility of the country's National Risk Assessment has led to an ongoing evaluation process that is informed by all relevant sectors to refine risk scenarios and incorporate new knowledge. The OECD describes national risk assessments as "an essential tool for supporting a country's overall resilience" (OECD, 2017a).

The potential for enhanced integration of DRR and adaptation through risk assessments is further limited by the five-year time horizon applied to the AHRA (PS, 2012). By limiting the time frame to five years, the AHRA excludes consideration of the long-term impacts of climate change and gradual socio-economic developments. The methodological guidance for conducting the AHRA emphasizes the importance of assessing the likelihood of risk scenarios based on historical data, further undermining the ability to integrate climate change (PS, 2012). It is crucial to incorporate new climate models and methods to help improve the robustness of assessments and the resulting strategies for managing climate-related risks (Eyzaguirre *et al.*, 2018). Finally, the impacts of compound extremes (the occurrence of simultaneous events) and the risks associated with cascading infrastructure failures are generally not reflected in current risk management (Lall *et al.*, 2018). Where these interconnections are poorly understood, risks are likely to be underestimated (CCC, 2016).

At the individual or household level, information needs to be conveyed in an accessible way, starting with the awareness that a risk exists and then followed up with a clear definition of roles, responsibilities, and accessible strategies to manage the risk (St Amour-Gomes *et al.*, 2018). A 2016 survey found that only 6% of Canadians living in a designated flood risk area were even aware of their risk (Thistlethwaite *et al.*, 2017). Providing guidance to individuals on how best to use available information through social activities, such as youth education programs and open houses at community emergency management facilities, is one way to increase the accessibility of information (FEMA, 2011).

Underreliance on Indigenous and Local Knowledge undermines disaster resilience

Globally, ILK is seldom included in DRR (Kenney & Phibbs, 2015). Addressing this deficit is not a simple matter of contacting Indigenous Peoples and asking for their input; rather than relying on such an extractive approach, different ways of knowing should be considered from the outset in conceptualizing risk and resilience. In the Panel's view, the recognition of Indigenous knowledge as a distinct methodological approach rather than as means of supplementing current practices provides DRR practitioners with an understanding of conservation and protection that is deeply connected to stewardship and community. For example, in interviews with Métis firefighters, it was found that by respecting and returning to ILK practices, many individuals viewed their work as a means of appreciating and preserving the balance of nature, protecting not only the land and communities upon it but also the identities embedded within the associated space (Mauro, 2020). Furthermore, many Indigenous communities are reluctant to share knowledge with governments and other settler systems they mistrust (Thomassin *et al.*, 2019). There are concerns around the appropriation of knowledge by researchers based on colonial research practices and the potential loss of intellectual property, therefore the sharing of this knowledge by Indigenous Peoples should not be assumed (Spak, 2005; Scott *et al.*, 2012). Moreover, it is important to recognize that even when ILK is willingly shared, it cannot always be bridged with other sources of knowledge. Fundamental differences among various knowledge systems exist and can create an additional barrier to the effective compilation of information (CCA, 2019a).

In the case of British Columbia's 2017 flood and wildfire season, one study noted that knowledge was offered by Indigenous communities about local roads, watercourses, and weather patterns in relation to flooding and wildfire events, but this information was seldom used (Abbott & Chapman, 2018). Surveys of Indigenous communities in British Columbia have repeatedly brought up the need for better planning and the incorporation of cultural considerations and knowledge into response coordination (Abbott & Chapman, 2018). In the same study, frontline responders also noted the challenges in attempting to understand and incorporate Indigenous knowledge during emergency responses. These results highlight the need to begin relationship-building and cooperation channels early, sustain contact, build trust, and create local networks that actively monitor and report on environmental changes before emergencies and disasters occur (Abbott & Chapman, 2018; Manrique *et al.*, 2018). Failure to acknowledge the relevance of ILK to DRR entrenches patterns of racialized disadvantage and marginalization, increasing future vulnerabilities (Howitt *et al.*, 2012). The underrepresentation of Indigenous Peoples in firefighting has been identified as one manifestation of this, where technical and post-secondary education requirements appear to be privileged over land-based, lived fire experience (FireSmart Canada, 2020).

4.1.3 Application of Information

A disconnect exists between information providers and decision-makers

Weaver *et al.* (2013) observe that "information may be scientifically relevant without being decision-relevant." Climate scientists may not have a good understanding of the needs or level of knowledge of some users (Porter & Dessai, 2017). An analysis of the development of climate projections developed by the United Kingdom's Met Office found that scientists generally expected users to have a requisite understanding or at least be able to make an effort to develop that understanding. These scientists also did not see it as their role to develop a detailed appreciation of user needs and instead saw this as the role of intermediaries. Interviews with climate scientists suggested they "are often aware of different users, with different needs, but feel unable to respond to them due to a lack of institutional rewards and priorities or due to the practical difficulties involved in satisfying the different needs of different users" (Porter & Dessai, 2017). This issue extends to decision-support tools as well, with some tools being ineffective due to a weak understanding of user needs, priorities, and capacities (U.S. National Research Council, 2010). Co-development of tools is called for to foster a greater sense of mobilization, engagement, and ownership among these groups (U.S. National Research Council, 2009).

Nationally, the variety of approaches, scales, and methodologies employed in risk assessments makes it difficult for stakeholders to compare hazards, vulnerabilities, and exposures between jurisdictions, and to guide appropriate responses to hazards (Henstra, 2017; Tymstra *et al.*, 2020). Pulling these disparate sources together is complicated by reliance on different formats, definitions, and scales, both within and among the various subject fields or organizations that comprise DRR and adaptation (Bauer & Smith, 2015). This lack of interoperability — a key barrier identified by those working to transfer climate knowledge between parties — is the inevitable consequence of siloed approaches to research and programming and limits effective coordination among DRR stakeholders and policy-makers (Bauer & Smith, 2015; Henstra, 2017).

This disconnect between information providers and decision-makers also extends to the ways in which available information is accessed and used. As Bauer and Smith (2015) note, "[i]t is increasingly the case that what [decision-makers] need is already out there in the 'sea of information' but [the issue is that it] cannot be found." As such, guidance is required to help decision-makers recognize the most relevant sources of information for their particular needs (Bauer & Smith, 2015). Decision-making is most effective when users are aware of how to adapt to the strengths of the data that are currently available, as well as to the limitations of what can reasonably be made available in the future by information providers.

4.2 Promising Approaches

Several strategies exist to address some of the barriers and challenges outlined above. Promising approaches include making strategic investments to expand the existing knowledge base, meaningfully and actively engaging with Indigenous Peoples and their knowledge systems, improving strategies for decision-making under uncertainty, integrating climate projections into risk assessments, and better connecting information with decision-makers.

4.2.1 Improving Current Sources of Information

Enhancing the availability of information necessary for integrated risk assessments will improve the quality of decisions

A reliable, consistent, and complete set of disaster data is crucial for understanding and managing disaster trends (RCNNDA, 2020). Eyzaguirre *et al.* (2018) recommend that the CDD be enriched through actions such as "improved reporting, data access, tracking of issues, accountability, ability to provide policy guidance, cost accounting, [and] types and consistency of climate events." Given the social and economic impacts of disasters in Canada, the Panel notes that a highly sophisticated tracking system — along the lines of that developed by Johns Hopkins University to track the COVID-19 pandemic (JHCRC, 2021) — is warranted. Enhanced and consistent collection of disaster data could help inform risk assessments and monitor the results of DRR investments (OECD, 2016a). In the United States, the National Centers for Environment Information tracks and assesses climate events that have significant social and economic impacts (NCEI, 2021). Its Billion Dollar Weather and Climate Disasters database integrates data from both public and private sectors, providing users with a comprehensive and consistent record of disasters with costs equalling or exceeding $1 billion in damages. Disaster data is available dating back to 1980, allowing decision-makers to track and compare financial losses associated with temperature and precipitation trends and extremes (NCEI, 2021). The Government of Japan collects data on all water-related disasters, both in the immediate aftermath and in an annual survey of local governments that dates back to 1961 (Amano, 2013; OECD, 2016a). Collection of this data is mandated under the country's statistics act, and the methodology enables the consistent and comparable collection of information across the country. Data on damages to households, public infrastructure, and public services are all compiled and published (Amano, 2013).

Existing information gaps can be filled strategically based on the needs of users. The need for enhanced weather monitoring, particularly in Northern Canada, is widely recognized (ECO, 2018; Mekis *et al.*, 2018; ECCC, 2020a). Enhanced public involvement is one avenue for gathering necessary data. Municipalities could strengthen their understanding of flood risks (while at the same time fostering community awareness) by eliciting community input. Another mode of public participation is citizen science initiatives where local observations can be logged and shared with municipalities, be it through photos of flood damage, water level monitoring, or other real-time observations (Henstra & Thistlethwaite, 2017). In North Carolina, the iFlood program includes an app for public reporting of flood images and locations and is intended to help researchers at the Woods Hole Oceanographic Institution improve its flood modelling (WHOI, 2021). Similarly, Vancouver's VanConnect app can be used by residents to report non-emergency flooding in public spaces as well as to receive up-to-date news and emergency information (City of Vancouver, n.d.-a, n.d.-b). By uploading a photo and description of the issue as well as GPS coordinates, residents using the app can request services from the city at any time (City of Vancouver, n.d.-a). The Inuit Field Training Program, run by ECCC in partnership with the community of Coral Harbour, is another example of an effective citizen science initiative that works to build the capacity of local youth to conduct environmental monitoring (ECCC, 2019b).

Courtesy of Environment and Climate Change Canada (ECCC)

Figure 4.1 Students Participating in the Inuit Field Training Program

Another way to fill information gaps is through the creation of monitoring networks. In British Columbia, the Pacific Climate Impacts Consortium has begun collecting and streamlining information from a network of province-wide observation stations (PCIC, n.d.). The data gathered from each observation station is uploaded into a provincial climate data set, providing users with a comprehensive set of weather and climate observations in an accessible and interactive format (PCIC, n.d.). At the national level, ECCC's Network of Networks initiative is being developed to strengthen Canada's capacity to monitor severe weather and climate events (ECCC, 2018a). In order to do so, the initiative seeks to expand the ECCC's current climate and weather database by incorporating data from observation stations in other networks operated at the regional, provincial, and territorial levels, ultimately improving access to relevant weather and climate data for decision-makers (ECCC, 2019a). In the Panel's view, the collection of such data, especially as it relates to extremes, can enhance the integration of DRR and adaptation as it aids in supporting informed decision-making processes related to future adaptation processes and practices.

Indices have the potential to provide simple, accessible information to a range of decision-makers. The U.S. Federal Emergency Management Agency has developed a National Risk Index, which offers a web-based interactive map providing local-level information on 18 natural hazards, including coastal flooding, heat waves, hurricanes, and forest fires (FEMA, 2020). Risk is assessed based on the likelihood and consequence of a hazard unfolding (reflected in expected annual monetary loss), social vulnerability, and community resilience (FEMA, 2020). To date, this index only captures climate change insofar as it incorporates the National Oceanographic and Atmospheric Administration's sea-level rise projections (Frank, 2020). FEMA (2020) identifies the following uses for this index:

> *update emergency operations plans; enhance hazard mitigation plans; prioritize and allocate resources; identify the need for more refined risk assessments; encourage community-level risk communication and engagement; educate homeowners and renters; support enhanced codes and standards; inform long-term community recovery.*

Damage curves[12] that support calculations of impacts of hazard events are also needed for quantitative risk assessment (Lyle & Hund, 2017). More specifically, Lyle and Hund (2017) call for the development of "the building blocks of natural hazard risk assessment," namely:

1. *A standardized, complete, and accessible set of hazard maps, starting with flood hazard.*

12 Damage curves express the scale of damage relative to the scale of the hazard.

2. *A standardized, complete, and accessible set of vulnerability information collected at a fine (property-level) scale.*

3. *Locally relevant and up-to-date fragility/damage curves. At first, focused on empirical-based flood damage curves.*

4.2.2 Engaging with Indigenous and Local Knowledge

Indigenous and Local Knowledge can enhance community disaster resilience when accessed in respectful ways

ILK has an important role to play in improving the understanding of risks and actions that can enhance resilience, especially at the local level. In the words of the UN Human Rights Council (2014), "Indigenous communities hold time-tested knowledge and coping practices developed through their intimate connection with their natural surroundings that make them resilient to climate-related natural hazards and disasters. This knowledge is a living practice, which can adapt in response to changing circumstances."

These worldviews represent sources of community-wide resilience and should be recognized by other actors involved in DRR throughout the process of engagement and relationship-building (Marteleira, 2017). For example, traditional approaches to fire planning and ignition can reduce the risk of "bad fires" (FireSmart Canada, 2020). In British Columbia, First Nations approaches to fuel management could play a role in reducing wildfire risk (Abbott & Chapman, 2018). When Indigenous fire stewardship is factored into planning alongside Western science, considerations of culture, health, ILK, inherent rights, respect, responsibility, and stewardship can be braided into the overall approach (FireSmart Canada, 2020).

Applying ILK to integrate DRR and adaptation can provide a range of benefits, including community empowerment, effective implementation through plans tailored to the local context, and an ability to reach community members and raise awareness through informal means and lessons that can be adapted to apply to other communities facing similar risks or with similar geographies (UNISDR, 2008). "Translating scientific information and Traditional Knowledge into action" is one of the five key measures to build resilience identified in the Pan-Canadian Framework (GC, 2016). Inuit Tapiriit Kanatami has also highlighted the importance of integrating Inuit knowledge into climate policies (ITK, 2016).

The Indigenous Community-Based Climate Monitoring Program funds community-led monitoring of the climate and the impacts of climate change and is intended to help bridge various sources of knowledge, including ILK, so they can be used together to inform decisions (CIRNAC, 2019). The long history of environmental observation and natural resource management practised by Indigenous communities can offer key place-based insights on climate change impacts to decision-makers (Vodden & Cunsolo, 2021). Community-based monitoring can additionally elevate the role of Indigenous communities in environmental governance and be applied to assert Indigenous sovereignty and jurisdiction, but it risks falling short when the ultimate decision-making authority — and thus, the power to change a situation — is not shared (Wilson *et al.*, 2018; Reed *et al.*, 2020).

The Xwisten First Nation worked with the First Nations' Emergency Services Society to develop a fire management framework that incorporates cultural burning practices and placed ILK alongside prescribed burning science in an effort to manage climate change impacts and reduce fire risk (Xwisten Nation *et al.*, 2020). In this instance, community engagement, revitalization of cultural practices, enhanced food production, and risk reduction were all positive outcomes of this undertaking (Xwisten Nation *et al.*, 2020).

Additionally, it is important to recognize the value of protecting and preserving places of cultural and historical significance that are threatened by climate-related hazards. Fort Conger in Nunavut, alongside other heritage sites in the Arctic, has experienced significant damage due to increased freeze–thaw cycles; changes in ice, snow, and water accumulation; and increased levels of fungi and rot due to the warming Arctic temperatures (Dawson, 2016). By actively preserving cultural heritage sites like Fort Conger, decision-makers can invest in DRR practices that further support ILK and increase community resilience in alignment with the Sendai Framework (UNISDR, 2015; UNDRR, 2017).

4.2.3 Informing Decisions Under Uncertainty

Choices about reducing disaster risks are subject to a range of significant uncertainties: alongside the changing climate, socio-economic trajectories, land-use choices, and resource use are also major sources of uncertainty (Weaver *et al.*, 2013). The presence of significant uncertainty can be particularly problematic when decision-making is taking place under a predict-then-act model focused on seeking robust solutions (Lemos & Rood, 2010; Weaver *et al.*, 2013). This latter approach could use scenario analysis to identify solutions that perform well under a range of possible futures (Weaver *et al.*, 2013). Pursuing no-regrets options that provide gains under all scenarios and/or offer sufficient co-benefits to be worthy of the investment (Section 3.2.1) are other approaches to navigating decision-making under uncertainty (Lemos & Rood, 2010).

Risk communication at the community level needs to be explicit in its statement of uncertainty

There is a tendency to overlook likelihood information that falls below a threshold of concern, and when there is uncertainty about likelihood, this vagueness can lead individuals to discard low-risk events entirely (Meyer & Kunreuther, 2017). Framing is one element of this. Uncertainty can make risk information difficult to interpret. For instance, an individual may dismiss a 1-in-100-year flood event as a remote possibility but react very differently to hearing that there is a 63% chance of such a flood occurring over the course of the next 100 years, or being told that the chances of such a flood occurring over the course of a 25-year period are greater than 1-in-5 (Meyer & Kunreuther, 2017). All of these statements are based on the same underlying data, but their meanings will be interpreted differently. Framing risks in an honest way that includes the worst-case scenario while providing opportunities for action can also motivate investments in resilience (Kunreuther, 2015; Gneezy *et al.*, 2020).

4.2.4 Integrating Climate Projections in Risk Assessments

All-Hazard Risk Assessments that incorporate climate projections offer the most tangible expression of integration

Integrated risk assessments acknowledge and incorporate information on various elements of risk, such as the probability and severity of impacts, considerations for multiple hazards occurring both simultaneously and separately, and interdependencies that may result in the potential for cascading risks (EEA, 2017). Lyle and Hund (2017) underscore the importance of quantitative risk assessments as "invaluable in understanding the tradeoffs between mitigation actions (including no action) and allow[ing] for more transparent and robust decision-making for risk reduction" however, they also note that, in Canada, these types of assessments are few and far between. Information deficits and a lack of professional capacity are the two biggest barriers to moving forward on this front (Lyle & Hund, 2017).

British Columbia's recent province-wide climate risk assessment investigates 15 risk events that could become increasingly likely by mid-century in a changing climate (MECCS, 2019). The assessment considered a wide array of consequences to natural systems, human health, the economy, and communities. Although expansive in its assessment of climate-related disasters, it did not integrate certain critical disaster risks, such as those relating to earthquakes (MECCS, 2019), and as a result, does not allow decision-makers to assess the resources warranted by climate-related risks relative to other risks facing the province. The value of this assessment is further limited by the lack of integration between the province's climate risk assessment and Emergency Management BC's Hazard, Risk and Vulnerability Analysis tool. Despite acknowledging the importance of climate change to hazards, risk, and vulnerability, the Hazard, Risk and Vulnerability tool does not consider climate change a risk in itself, nor does it incorporate the results of the climate risk assessment into its analysis (EMBC, 2020).

The United Kingdom undertakes a climate change risk assessment on a five-year cycle (CCC, 2021). Mandated under the *Climate Change Act 2008*, this assessment considers risks and opportunities associated with a changing climate and advises on the urgency of action to manage these. This analysis factors in anticipated changes in the future climate, socio-economic developments, interactions among risks, indirect and distributional impacts, institutional barriers, and adaptive capacity (CCC, 2021). Despite these strengths, the United Kingdom's climate change risk assessment does not consider the procedures and practices involved in DRR, focusing almost entirely on adaptation.

In the United States, the First Street Foundation created a national flood risk assessment that integrates climate projections (First Street Foundation, 2020b). Available down to the individual property level across the United States, this tool offers new insights about flood-related risks that could come about through pluvial, river, and coastal flooding associated with tides and storm surges. This analysis extends out to 2050, using global climate models to inform expected flood risks over time. It also reveals many previously unidentified flood risks and, in aggregate, suggests that previous analyses underestimated risks. Covering 142 million properties overall, the model finds that 21.8 million properties are currently at risk of flooding, but that the number of properties at risk will grow by 7.7% to 23.5 million by 2050 in a changing climate (First Street Foundation, 2020a, 2020b).

Another important consideration for integrating DRR and adaptation through AHRAs is the extent to which vulnerability analyses are incorporated into their overarching methodology. In the Panel's view, DRR and adaptation practitioners can utilize tools such as the Gender-based Analysis Plus (GBA+) framework or Participatory Capacity and Vulnerability Analysis frameworks to incorporate critical information that may otherwise be overlooked in traditional risk assessments. By ensuring that AHRAs are informed by an active understanding of vulnerability, decision-makers can identify structural inequalities that entrench risk while enhancing community understanding of hazards and the factors that increase vulnerability to those hazards (Oxfam, 2010, 2013).

4.2.5 Connecting Information with Decision-Makers

Fit-for-purpose tools can help decision-makers access and apply information to enhance disaster resilience

The Coordinated Regional Climate Downscaling Experiment (CORDEX) and the Coupled Model Intercomparison Project (CMIP) are considered two of the main generators of global climate scenario data. The CORDEX uses dynamic and statistical downscaling techniques to provide researchers and decision-makers with the high-resolution climate information needed for risk assessment and action in support of adaptation (Giorgi *et al.*, 2009; WCRP CORDEX, n.d.-a, n.d.-b). The CMIP compiles modelling data in a standardized format, allowing researchers to assess model performance while analyzing "past, present, and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context" (WCRP, 2017). CMIP data and the corresponding analyses are publicly available and form the basis for many climate assessments and negotiations (Carlson *et al.*, 2017).

A web portal that integrates multiple types and sources of information and provides a user-friendly and interactive interface around the themes relevant to decision-makers could enhance the value of information resources that do exist (U.S. National Research Council, 2010). The Climate Atlas of Canada is one such tool that incorporates data alongside maps and stories to paint a more fulsome picture of the risks associated with climate change (Climate Atlas of Canada, n.d.). Interactive maps show how select climate variables are expected to change over time across the country. Data on a range of variables, including hot days and heavy precipitation, can be downloaded at the local level. Videos and articles build further understanding through profiling adaptation efforts unfolding across the country (Climate Atlas of Canada, n.d.).

Interactive story maps are another web-based tool for climate data communication. For example, the story maps used by the City of Calgary allow individuals and businesses to research the flood risk of their homes, workplaces, and frequently travelled routes in an easy and accessible manner (City of Calgary, n.d.). Each colour on the map indicates a different likelihood of flooding based on the calculated percent chance of natural conditions producing overflow of the river within a given time period (City of Calgary, n.d.).

When it comes to putting risk information in the hands of households, accessibility, consistency, salience, action orientation, and multiple communication formats can all help (Coppola & Maloney, 2017). Mandatory hazard disclosures can improve awareness of risks facing a property, including flood risks (Thistlethwaite & Henstra, 2017). These kinds of disclosures are fundamental for informed individual decision-making, yet they are underutilized by governments for fear of property depreciation and legal liability (Press, 2017; Thistlethwaite & Henstra, 2017). Creating a legal requirement for the disclosure of flood risks at the time of home purchase could foster greater risk awareness (Thistlethwaite & Henstra, 2017). The time of home purchase is a key opportunity to create awareness through real estate agents and home inspectors (St Amour-Gomes *et al.*, 2018). For example, Edmonton offers flood assessments to homeowners free of charge (Feltmate & Moudrak, 2021). In the United States, the online real estate marketplace Trulia overlays sales properties on maps that show the history of floods, wildfires, and other natural hazards in the area (Hill & Martinez-Diaz, 2020). In Miami-Dade County, Florida, properties located in high flood-risk zones must clearly disclose these risks to prospective buyers (Miami-Dade County, 2021).

Intensity-duration-frequency (IDF) curves provide essential information to decision-makers planning water-related infrastructure and managing watersheds (ICLR & FIDS, 2021). IDF curves require continual updating in order to accurately adjust for the anticipated impacts of climate change (Schardong *et al.*, 2020). Western University has developed an online tool that can be used to generate up-to-date IDF curves pulling from ECCC rain monitoring data and allows for scenario analysis to capture uncertainty (ICLR & FIDS, 2021). Considerable uncertainty exists in regard to updated IDF curves (Cook *et al.*, 2020). Guidance, including modelling guidelines set by state and local agencies or, in the absence of guidelines, the inclusion of transparent uncertainty metrics, can help decision-makers integrate IDF curves into the planning process (Cook *et al.*, 2020).

Climate data and information must also be packaged in a way that supports informed decision-making on behalf of lenders, investors, and underwriters. Investors, for example, are aware of the need for and benefit of climate scenario analyses but lack the appropriate guidance regarding how best to use them in practice to effectively advance the use of forward-looking industry assessments (Pinchot, 2019).

Engineering guidelines that integrate adaptation enable better design and improve the long-term safety of physical assets

Engineers require detailed guidelines and best practices to incorporate climatic uncertainty into infrastructure development (Roy *et al.*, 2017). British Columbia's Ministry of Transportation and Infrastructure has issued a technical document detailing high-level guidance for consulting with climate data providers and resources (Roy *et al.*, 2017; Gov. of BC, 2019). Engineers Canada (2018) has released a national guideline to inform engineering professionals on the relevance of integrating adaptation into their practice. This guideline includes information on best practices, guiding principles, and how to produce a clear record of outcomes for infrastructure and buildings (Engineers Canada, 2018). Another valuable tool is the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol, which reviews historical climate information and projects "the nature, severity, and probability of future climate changes and events" (PIEVC, n.d.). This type of information can provide estimates of climate-related impacts on infrastructure, including which components are deemed to be at higher risk, helping engineers make more informed decisions and design adjustments (PIEVC, n.d.). Similarly, in 2019, the Ontario First Nations Technical Services Corporation published the First Nations Infrastructure Resilience Toolkit, which is intended to support engineers in the design of climate-resilient infrastructure (OFNTSC, 2020). It incorporates ILK with climate data to help First Nations communities develop risk management measures to identify and address climate change risks to existing infrastructure. The Toolkit was developed based on the experience of First Nations communities with the PIEVC Protocol, recognizing that the inclusion of unique, community-based processes fosters greater understanding and acceptance of outcomes (Stantec, 2019).

Presenting disaster risks as an economic and financial issue, including through corporate disclosures, can raise awareness and prompt action

Public companies and investors struggle to understand and value shifting corporate risk profiles in a changing climate, tending to discount climate-related risks as too uncertain and temporally distant to value (TCFD, 2017). There is increasing attention paid to the role financing could play in encouraging resilience to climate change and other disaster risks (Section 5.2.1). According to the Task Force on Climate-related Financial Disclosures (TCFD), "[o]ne of the essential functions of financial markets is to price risk to support informed, efficient capital-allocation decisions" (TCFD, 2017). These disclosures could also be of value to securities commissions, central banks, credit rating agencies, and boards of directors (Bolton *et al.*, 2020; Feltmate *et al.*, 2020). In particular, when a board of directors is made aware of material risk, management may be incentivized or even required to act appropriately, thus spurring on adaptive action (Feltmate *et al.*, 2020).

Ouranos, a not-for-profit organization dedicated to climate change modelling, undertook a tailored cost-benefit analysis of the various adaptation options available to address coastal erosion (and the related risk of damages from sudden collapses along coastal cliffs) along the waterfront in Percé, Quebec. Planned retreat and beach nourishment were identified as the most cost-effective options for different sections of the coastline (Circé *et al.*, 2016). The research underscored the importance of tourism to the town and demonstrated the value of relying on an NBS for protection (Circé *et al.*, 2016). Motivated by the results of this analysis, the town revamped its shoreline, making space for the beach as a tool to build resilience (Marché Municipal, 2019). The beach was redesigned to dissipate waves before they reached the town. The town was ultimately rewarded with a national urban design award for this work (Marché Municipal, 2019).

Knowledge brokers are valuable intermediaries that can enable two-way communication between researchers and information users

The importance of boundary organizations that work between experts and information users is well-recognized and called for to reconcile different perspectives and requirements between those groups (Cash *et al.*, 2003; Bauer & Smith, 2015; Hill & Martinez-Diaz, 2020). Information is most helpful for guiding decision-making when it is viewed as salient, credible, and legitimate. Cash *et al.* (2003) unpack these three terms as follows:

> *[C]redibility involves the scientific adequacy of the technical evidence and arguments. Salience deals with the relevance of the assessment to the needs of decision makers. Legitimacy reflects the perception that the production of information and technology has been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of opposing views and interests.*

Mediation also plays a key role in addressing fundamental "tradeoffs among salience, credibility, and legitimacy" by establishing the nature of and rules for engagement between the scientists and decision-makers (Cash *et al.*, 2003). However, such undertakings face significant challenges: scientists may be uncomfortable with this work or even opposed to it, and decision-makers and other information users such as investors or lenders may lack confidence that such a process will yield useful results (Cash *et al.*, 2003). Climate services are expanding in response to these needs (Box 4.1).

Box 4.1 Climate Services

The U.S. National Research Council (2010) identifies the following core climate service functions:

- *A user-centred focus that responds to the decision-making needs of government and other actors at national, regional, and local scales;*
- *Research on user needs, response options, effective information delivery mechanisms, and processes for sustained interaction with multiple stakeholders;*
- *Enhanced observations and analyses designed specifically to provide timely, credible, authoritative, relevant, and regionally useful information on climate change and vulnerability, and effectiveness of responses;*
- *Trustworthy and timely climate modelling and research to support federal decision-making about limiting emissions and adaptation;*
- *A central and accessible web portal of information that includes a system for sharing response strategies and access to decision-support tools;*
- *Capacity building and training for linking knowledge to action across the nation; and*
- *An international information component.*

The resulting climate information then needs to be linked to other types of data that reflect physical assets, population characteristics, economic considerations and other variables to provide a picture of vulnerability and exposure alongside climate-related hazards (U.S. National Research Council, 2009).

Launched in 2018, ECCC's Canadian Centre for Climate Services was established to build resilience across Canada by providing access to climate information that can support decision-making and help build capacity across the system (GC, 2020). Regional climate change organizations, including Ouranos, the Pacific Climate Impacts Consortium, the Prairie Climate Centre, and ClimateWest, offer climate information on a regional basis alongside other country-wide databases, including Climate Data Canada, the Climate Change Hazards Information Portal, and the Canadian Climate Data and Scenarios Portal. The Panel observed that demand for these services is building as a wider group of decision-makers seeks to understand the implications of climate change for their business. However, until data on disaster and climate risks is tied to existing decision-making processes, this kind of information will be underutilized.

Successful translation needs to go both ways, however, with researchers needing to find ways of incorporating and respecting place-based knowledge in scientific research. Knowledge brokers[13] can help overcome challenges associated with different cultures and uses of technical language among researchers and practitioners, institutional reward systems that do not encourage collaboration and research dissemination, and a lack of upstream engagement of practitioners in research planning (Fothergill, 2000). Trust also affects what information decision-makers use, requiring confidence in sources and in those interpreting and applying the information (Bauer & Smith, 2015). The U.S. National Research Council (2010) emphasizes the importance of the process as well as the product, highlighting that partnerships among information producers and users can build trust. Research by Fothergill (2000) has further demonstrated that the development of interpersonal relationships, sustained communication, and the desire for further professional integration moving forward are critical in narrowing the gap between researchers and practitioners. Knowledge brokers have the ability to address this deficiency.

4.3 Capabilities

In order to help decision-makers integrate DRR and adaptation, key information-related capabilities can be developed. These capabilities include enhancing sector-specific abilities and utilizing knowledge brokers as a means of effective risk communication between sectors.

4.3.1 Strengthening Capabilities in Regulated Professions

There is scope for enhancing the consideration of disaster resilience in several regulated professions, including engineering, planning, landscape architecture, and accounting. Engineers Canada developed the PIEVC Protocol, an asset-specific engineering risk assessment tool used to consider climate risks, as well as the Infrastructure Resilience Professional designation, which requires "training in asset management, risk management, the PIEVC Protocol, climate science, and climate change law" (Engineers Canada, 2019, n.d.). Engineers Canada no longer runs these programs (Engineers Canada, 2019), which, in the Panel's view, leaves a potential blind spot in the clear standardization of climate risk in Canada as, without independent engineering oversight, the PIEVC Protocol can no longer be considered an independent framework. The future of the PIEVC Protocol is thus uncertain despite its early value to the engineering sector as a reputable and predictable tool to apply to assessments of climate change impacts on critical

13 For the purpose of this report, knowledge brokers are understood as "those people, organisations or initiatives that use climate related information to facilitate the transfer of climate knowledge from one person or organisation to another" (Bauer & Smith, 2015).

public infrastructure. Although there are several related frameworks, such as ISO Standards and Envision, the Panel believes that they do not serve the same ultimate purpose, and as a result, there remains a gap in the Canadian industry in this important space, which could be addressed by a standard-setting organization, an industry organization, or regulators.

The Canadian Institute of Planners has developed a model standard of practice that establishes expectations for considering climate change in planning work and provides a framework for conducting the necessary analysis (CIP, n.d.). The Canadian Society of Landscape Architects has developed a series of four primer manuals that provide guidance on the development of resilient communities informed by climate science (CSLA, 2018). The primer manuals also provide extensive reference materials intended to support informed decisions within the field (CSLA, 2018). Additionally, Chartered Professional Accountants Canada has developed guidance for accountants on supporting their clients in adapting to climate change (CPA, 2016).

4.3.2 Knowledge Brokers

Abundant scientific information is available to proceed with integrated DRR and adaptation initiatives. What is lacking, however, is the effective communication required to facilitate this integration (Section 2.3.2). Although publicly accessible data portals exist, the information available is often packaged in ways that obstruct communication and collaboration among climate and risk scientists and practitioners (Birkmann & von Teichman, 2010). In the Panel's view, knowledge brokers play a critical role in making that information accessible, relevant, and trusted, especially as demand for climate change and adaptation data increases. In particular, the release of the TCFD recommendations has increased business demand for appropriately scaled information about future climate at the level of business decision-making (Fiedler *et al.*, 2021). Moving forward, businesses will require the support of climate service providers to help them locate and interpret existing climate information (Fiedler *et al.*, 2021). Furthermore, increased utilization of up-to-date climate data has been observed, with the recognition that most municipalities seek information packaged in ways that reflect "local examples (i.e., case studies), funding, and technology and design alternatives" (FCM *et al.*, 2019). The capacity to meet these demands is ramping up over time, but the Panel did not identify any data that quantified the scale of demand or supply.

4.4 Key Opportunities for Integration

Information is an essential ingredient for the successful integration of DRR and adaptation. Decision-makers require accurate and up-to-date information on hazards, exposure, and vulnerability to effectively understand and address disaster risks in a changing climate as well as to guide resource allocation decisions in ways that most effectively manage a wide range of disaster risks. In order to facilitate this, three key practices stand out as effective opportunities for integration. The first is increasing the availability and accessibility of information for decision-makers. Through processes and practices, such as fit-for-purpose tools, regular updating of data portals, and AHRAs, decision-makers will be equipped with the information that they require regarding both climate change and disaster risks. This will allow decision-makers to effectively integrate the consideration of different hazards as well as climate projections into decisions moving forward. Second, priority must be given to effective and broad-reaching risk communication. Moving beyond simply making risk visible to creating an active process for raising awareness and sharing knowledge can enable decision-makers to address the various needs of communities in a timely and comprehensive manner. These needs, which are often the result of various overlapping risk and vulnerability factors, highlight how interconnected the impacts of disaster risks and climate change are and how pivotal the integration of these considerations and approaches are for effective decision-making practices. Of critical importance to risk communication is the recognition and incorporation of ILK. Lastly, to effectively integrate DRR and adaptation, it is important to develop and support professional capabilities. Knowledge brokers can help decision-makers better understand and apply the information available to them by facilitating effective and meaningful communication among all parties involved. Ultimately, as the Panel underscores in Chapters 5 and 6, decision-makers need to be encouraged and even compelled to factor climate information into their planning and actions.

5

Insuring, Funding, and Investing in Disaster Resilience

5.1 Existing Barriers and Incentives

5.2 Promising Approaches

5.3 Capabilities

5.4 Key Opportunities for Integration

Chapter Findings

- Insurance programs can drive changes in behaviour and encourage resilient reconstruction when they feature expanded coverage that includes more assets and hazard types, risk-based pricing that discourages people from living in the most exposed areas, policy terms that support rebuilding better and in less exposed locations, and eligibility requirements that drive risk mitigation by establishing minimum standards for coverage.
- Investments in prevention are often more cost effective than recovery spending. Putting Canada's disaster relief programs on sustainable footing requires governments to shift spending from recovery to prevention. Public investments maximize their impact when they focus on those most at risk, including through support for strategic retreat (when warranted) and expanded insurance coverage.
- Financial disclosures of disaster risks will support investor engagement and appropriate corporate risk management.

Problems of inadequate insurance coverage are longstanding and drive up the costs of disaster recovery for taxpayers and households. Growing disaster risks in a changing climate create even greater financial exposure to uninsured losses, thus enhancing the importance of expanding insurance coverage. Failure to appreciate the impact of climate change on future disaster risks will lead to underinvestment in disaster resilience among private and public actors alike. When public funding for adaptation and DRR is fragmented, programming can be inefficient and may not be sufficiently flexible to meet the needs of funding recipients.

In the face of these challenges, there are several financial levers that can motivate (or discourage) disaster resilience. Insurance can encourage spending on protective measures and also provide a financial backstop in the event of a disaster. Scrutiny of disaster risks by investors can motivate firms to manage these risks more carefully. Public sector spending and funding programs can be fine-tuned to incentivize measures to build disaster resilience. This chapter explores the barriers and opportunities for integrating adaptation and DRR in insurance, investing, and public sector spending.

5.1 Existing Barriers and Incentives

Underinvestment in disaster prevention coupled with incoherent or poorly designed DRR and adaptation policies and programs significantly impede the integration of these two fields. This section identifies how these barriers manifest themselves, pulling in evidence from Canada and abroad.

5.1.1 Underinvestment in Disaster Mitigation and Insurance

Inadequate insurance coverage is a long-standing risk for households, companies, and governments

Swiss Re reports that of US$80.5 billion in total disaster losses reported in North America in 2018, only US$52.9 billion was insured (Swiss Re, 2019). Analysis of "The Beast," the major 2016 wildfire in the Fort McMurray area (Figure 5.1), found that over 25% of the losses were uninsured (Munich Re, 2017). While some level of self-insurance is rational, much of this protection gap can be attributed to a lack of risk awareness among consumers (Holzheu & Turner, 2018; Swiss Re, 2019). Consumers may not be aware they face certain risks, may assume coverage is provided through existing insurance, or may deem the risk too remote and the cost too high to justify purchasing insurance. In some instances, reluctance on the part of insurers to offer certain coverage can also play a role (Holzheu & Turner, 2018; Swiss Re, 2019). In Canada, overland floods tend not to be covered in home insurance policies (ICLR, 2021). While this coverage has become increasingly available in recent years, as of 2021, only one insurer offers coverage for overland flooding in high-risk areas (ICLR, 2021). Similarly, saltwater coastal flood protection is only offered by one insurer (ICLR, 2021). Protection for households and infrastructure exposed to permafrost thaw is also a key gap in the north, where there is uncertainty about the applicability of existing home insurance coverage to this emerging hazard (Eisenberg, 2018; Tsui, 2021). Underinsurance creates large liabilities for governments who ultimately bear many of these costs; not only must they rebuild public infrastructure, but they are also called upon to provide relief to individuals and businesses (Swiss Re, 2018; OECD & The World Bank, 2019).

The Canadian Press / Jonathan Hayward

Figure 5.1 Wildfire outside of Fort McMurray, Alberta, 2016

The challenges on First Nations reserves may be more acute. Many reserves face elevated wildfire and/or flood risks due to remoteness and limited access to emergency services, yet access to mainstream insurance products can be limited (Norbury, 2013; Puxley, 2015; FireSmart Canada, 2020). Reserve lands are community-owned, and thus home insurance tends to be negotiated at the community rather than the household level (Norbury, 2013). Long-standing issues with substandard housing and inadequate firefighting services discourage insurers from offering coverage and drive up prices when it is offered (Norbury, 2013). A 2011 federal report found that only 56% of First Nations communities have adequate fire insurance (Puxley, 2015).

Moral hazard and adverse selection can undermine the value of insurance for motivating investments in protection

When individuals perceive disasters to be the responsibility of the state, they are less likely to take the initiative to reduce their own vulnerability (Terpstra & Gutteling, 2008). Furthermore, trust in institutions may reduce the propensity of people to reduce their risk at a household level, creating a moral hazard (Penning-Rowsell, 2019). It is noteworthy, however, that research shows only a modest negative effect of public relief on insurance coverage (Kousky *et al.*, 2018). Although citizens expect governments to plan and be prepared for emergencies, the inherently diffuse costs and benefits of DRR impede public mobilization or lobbying in support of or against policies in the field (Henstra, 2013).

Moral hazard creates problematic incentives for people living in hazard-prone areas. Termed the *Samaritan's dilemma* (Buchanan, 1975), individuals who have reason to expect relief may thus choose to assume additional risk. When the state bears some of the costs of reconstruction, individuals are more likely to rebuild in exposed locations. As a result, the casualties and costs of the next disaster are higher than they would otherwise be (Shughart, 2011). In addition, the expectation that public assistance will be forthcoming reduces reliance on private insurance (Henstra & Thistlethwaite, 2017; Kousky *et al.*, 2018).

Adverse selection further exacerbates the insurance challenge, as customers facing the greatest risks are most likely to seek out coverage (Lamond & Penning-Rowsell, 2014). This can discourage insurers from offering coverage and lead to low program uptake. Adverse selection is a common challenge for flood insurance programs and can lead to increasingly unaffordable premiums for customers and untenable economics for underwriters (Lamond & Penning-Rowsell, 2014) (Box 5.1).

A host of cognitive biases lead to underinvestment in disaster mitigation and insurance

In addition to the general challenge of myopia described in Section 2.3.2, Meyer and Kunreuther (2017) identify "two forces that, acting in tandem, make investments in protective action difficult to sustain." First, while individuals retain some details of past disasters in long-term memories, the emotional impact tends to fade relatively quickly. It is often this emotional drive that would cause households to take action to protect against future disasters. Second, protective actions do not tend to generate positive reinforcements. Unless a future disaster should arise, the choice to purchase flood insurance year after year will not create any sense of reward (Meyer & Kunreuther, 2017). Empirical research bears this out. In a U.S. study, Gallagher (2014) found that insurance purchase rates jump immediately following a flood and then gradually taper back to the pre-flood baseline. Similarly, reductions in housing prices that immediately follow a flood tend to be relatively short-lived (Eves, 2002; Beltrán *et al.*, 2019). Moreover, homeowners do not reliably install their storm shutters in the face of a hurricane warning: the knowledge that installing the shutters is the right thing to do is in conflict with the instinct that they will probably not be needed (an instinct reinforced by past experience) (Meyer & Kunreuther, 2017). In addition, near-miss events are routinely misinterpreted as indicators of resilience. When a natural hazard unfolds but the consequences are minor, complacency increases. Dillon *et al.* (2011) find that households that experience near misses with hurricanes are less likely than others to purchase protective flood insurance or evacuate in the event of a hurricane.

When faced with uncertainty, individuals look to their peers for cues about how to respond. This *herding instinct* often serves people well but fails in an information vacuum (Meyer & Kunreuther, 2017). Lo (2013) found that the decision to purchase flood insurance was not tied to flood risks but was highly tied to an individual's belief about the social norm for purchasing insurance.

These individual biases influence the politics of disaster spending and can favour problematic approaches to managing disaster risks. For instance, nearsightedness also manifests itself at the political and bureaucratic levels. Despite the significant benefits of disaster preparedness spending, there is little political reward (Healy & Malhotra, 2009). In contrast, spending on disaster relief is heavily rewarded at election time. This incentivizes decision-makers to focus on the here and now rather than distant and unlikely events (Healy & Malhotra, 2009). These challenges become increasingly acute in a changing climate, where the need for adaptation is widely recognized but these biases are standing in the way of meaningful action (Meyer & Kunreuther, 2017).

5.1.2 Weaknesses in Policy and Program Design

Fragmentation across funding programs reduces resource efficiency and interferes with the integration of climate change adaptation and DRR

The Government of Canada runs numerous adaptation and DRR funding programs aimed at different constituencies, risks, and scales (PS, 2017b, 2019b; GC, 2019a; INFC, 2019a). This fragmentation creates significant administrative burdens for prospective participants who need to navigate this complex set of offerings and can reinforce and even necessitate counterproductive silos that impede efforts to integrate responses to DRR and adaptation (M. Redfern, personal communication, 2020). Misaligned eligibility criteria and program administration timing can impede integration (PS, 2020c). In some instances, demonstrating that climate change is the cause of an adverse event is highly challenging (Section 2.2.1) and can interfere with good projects being funded (M. Redfern, personal communication, 2020).

Some existing DRR programs have been criticized for their narrow scope. PS's National Disaster Mitigation Program has a budget of $225 million to cost-share investments to reduce flood risks through risk assessment, flood mapping, mitigation planning, and mitigation projects from 2015 to 2022 (PS, 2021). As the emphasis on all-hazards risk reduction grows, the National Disaster Mitigation Program has been criticized for ignoring the interplay among hazards and focusing only on flooding; provincial and territorial recipients indicated that an all-hazards program would be preferable (PS, 2020c). Tight eligibility criteria may restrict the ability of program administrators and recipients to develop projects that accommodate all future climate-related hazards (PS, 2020c).

When it comes to selecting the most important prevention and mitigation investments, communities understand their own needs best (INAC, 2017). Current centrally developed programs risk tying the hands of communities through program eligibility criteria, timelines, and centralized control over the types of projects that can be pursued. A 2017 evaluation of Indigenous Services Canada's Emergency Management Assistance Program (EMAP) identified this weakness and noted that First Nations communities wanted to be engaged in DRR in ways that develop their own capacity and self-reliance (INAC, 2017).

Recovery programs often support rebuilding in hazard-prone areas

After a disaster occurs, PS's Disaster Financial Assistance Arrangements program provides financial assistance to provinces and territories for response and recovery, covering certain governmental and individual costs not already covered through insurance or existing programs (PS, 2019b). This program has paid out over $5 billion since 1970 on a cost-shared basis, with the vast majority of these funds allocated to the recovery of public infrastructure (around 70% of funds) (IBC, 2019; PS, 2019b). Similarly, Indigenous Services Canada's EMAP provides support to First Nations communities across the four components of emergency management (prevention and mitigation, preparedness, response, and recovery) (ISC, 2019b). Between 2005 and 2018, this program disbursed almost $1 billion in funds, predominantly for response and recovery (ISC, 2019a) (Figure 5.2).

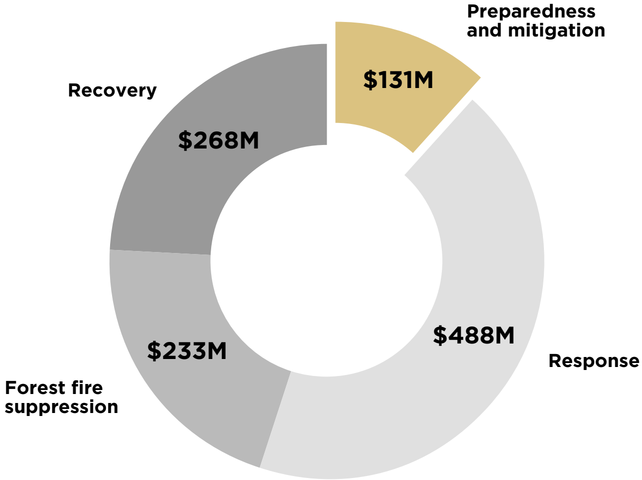


Figure 5.2 Emergency Management Assistance Program Costs Reimbursed by Spending Area (2005 to 2019 Totals)

The largest share of EMAP expenditures is allocated to response, followed by recovery and forest fire suppression. Preparedness and mitigation spending is the smallest area of expenditure.

This type of relief does not have any stipulations for municipalities or homeowners to rebuild outside of high-hazard areas or with increased risk-reduction measures (Thistlethwaite & Henstra, 2017). The fact that assistance is not risk-adjusted limits incentives for municipalities to mitigate risk (especially from flooding), knowing that any significant damage will be covered by the province (Thistlethwaite & Henstra, 2017).

The challenge of rebuilding in hazard-prone areas has been long recognized. Following Calgary's 2013 flood — which was, at the time, Canada's most expensive disaster — a voluntary buyout was offered to some residential property owners to avoid rebuilding expensive housing in the floodplain (Cryderman, 2013; Swiss Re, 2016). However, less than a third of eligible households chose to relocate, citing lower-than-market-value buyout offers or a preference to live with the risk and stay in their homes (Markusoff, 2018). Many instead received government financial support to rebuild in place, with the proviso that these homes would not be eligible for assistance in the event of future flooding (Cryderman, 2013; Markusoff, 2018). More recently, the Government of Quebec offered a buyout to some homeowners impacted by flooding (Boudreault, 2021).

Funding uncertainty and delays in resource flows may preclude building forward better, even when there is a desire to do so. For instance, EMAP generally issues reimbursements based on receipts after expenditures have been made. Delays in receiving reimbursement have been identified as a significant shortcoming by program recipients, in some instances even driving First Nations communities to rely on high-interest loans to allow for reconstruction to occur before receiving reimbursement (INAC, 2017). While expenditures to reduce the vulnerability of infrastructure to future disasters may be eligible expenses, this determination is made on a case-by-case basis (ISC, 2020). Uncertainty about eligible expenditures may deter relocation when this is warranted; in one case, relocation was considered eligible, but expenditures related to installing a septic system, which was an element of this relocation, were not eligible (INAC, 2017).

Insurance contracts can interfere with rebuilding in ways that enhance resilience in a future climate

In Canada, home insurance generally offers payouts to replace existing structures at the same location. This approach may discourage relocation to less exposed areas and may also interfere with rebuilding structures with more resilient materials (Malik, 2020). Policies may only offer the full replacement cost value of a home if it is rebuilt in the same location (even if that happens to be a floodplain) or may insist on rebuilding with the same non-fire-resistant materials in a fire-prone area (Northcross, 2019; Malik, 2020). Policies often do not even cover the additional costs of replacing a structure to meet the latest building code, let alone the full suite of measures that could make a structure fully adapted to a changing climate (Northcross, 2019; Virani Law, 2019). In California, without special coverage, homes at the wildland–urban interface will not have coverage to rebuild to new fire-resistant standards (Northcross, 2019). Northcross (2019) further observes: "at the same time that homeowner's insurance is inadequate to fund rebuilding to the resilience required by climate change, the state's insurance providers may not be able to sustain coverage at the current inadequate levels."

5.2 Promising Approaches

5.2.1 Incentivizing the Mitigation of Disaster Risk in a Changing Climate

An analysis of several elements of the National Research Council of Canada's Climate Resilient Buildings and Core Public Infrastructure Initiative estimates the anticipated savings for each dollar spent on several different mitigation measures: interventions that reduce basement flood risks in residential buildings are estimated to provide a benefit–cost ratio of 11:1 (that is, $11 in savings for each dollar spent); enhanced construction standards at the wildland–urban interface yield a 6:1 ratio, and highway bridge design modifications yield a 9:1 ratio (Porter & Scawthorn, 2020). In the United States, Healy and Malhotra (2009) estimated that $1 spent on preparedness saves $15 in future damages and notes that this kind of spending has the potential to offer near-term returns to elected officials, as $7 of these savings is achieved within a single election cycle. Recent U.S. analysis found the benefit–cost ratio of adopting up-to-date model building codes was 6:1 for riverine flood hazards and 10:1 for wind hazards (Porter *et al.*, 2019). Select retrofits to the existing residential building stock offered a benefit–cost ratio of 6:1 for riverine flooding and wind hazards. The considerable benefits offered by these interventions include those associated with avoided property damage, supplemental living costs and business disruptions, and economic representations of loss of life and health consequences (Porter *et al.*, 2019). While the resources required to prevent and mitigate disaster risks in a changing climate are recognized to be far lower than those required to recover from disasters after the fact, they are nonetheless considerable (Porter & Scawthorn, 2020). This once again underscores the need for deep reductions in GHG emissions going forward, which "is necessary to keep the cost of climate change adaptation under control" (Kovacs *et al.*, 2021).

In his former role as the governor of the Bank of England, Mark Carney referred to the "tragedy of the horizon," observing a mismatch between political and business decision-making time horizons and the time scales of climate change (Carney, 2015). The Panel underscores that valuing investments in prevention and freeing up the requisite financial resources are essential to minimizing losses over time. In fact, these risk-reduction investments may become essential for maintaining the sustainability and affordability of insurance in a changing climate (Golnaraghi *et al.*, 2016).

Investors can reward and even compel risk reduction

The TCFD argues that publicly traded companies should be disclosing material climate change and disaster-related risks to shareholders in the same way as other material financial risks (TCFD, 2017). This disclosure should include the governance and oversight of these risks; potential impacts on the business and the resilience of the organizations' strategy; plans to identify, assess, and manage these risks; and corresponding measures and targets (TCFD, 2017). While the TCFD focused on risks associated with transitioning to a low-carbon economy, physical risks of climate change impacts were also considered (TCFD, 2017). In particular, the TCFD identifies impacts on production capacity, workforce, early asset retirement, and increased operating costs as potential financial impacts stemming from the physical risks of climate change (TCFD, 2017). The Office of the Superintendent of Financial Institutions Canada identified four mechanisms through which an extreme weather event could affect banks, insurers, and pension plans: credit risks, the lower market value of investments, insurance losses, and damage to operations/premises (OSFI, 2021).

The TCFD recommendations were endorsed by the federally commissioned Expert Panel on Sustainable Finance and the Government of Canada (GC, 2019c, 2019d). Given provincial and territorial jurisdiction over securities regulation, full implementation of climate-reporting requirements will require close cooperation between federal and provincial governments (GC, 2019c). The Government of Canada is also working towards enhanced disclosures, in line with the TCFD, requiring federal Crown corporations to disclose climate-related financial risks (GC, 2021c).

Investors are well placed to encourage enhanced corporate resilience by requiring disclosure and allocating capital accordingly (TCFD, 2017). However, evidence to date suggests that investors are not adequately valuing these kinds of risks (IMF, 2020). Frank *et al.* (2021) call for changes in public disaster relief spending in the United States, in part:

> *to signal the market—to investors, municipalities, the credit rating agencies and others that the assumption that all disaster costs will be compensated is no longer robust. And once the market has that signal it will respond quickly with its own powerful incentives—in the form of insurance prices, bond ratings and prices, and flow of capital—that will encourage safer behavior.*

In one notable development, Canada's eight largest pension plans, which collectively represent $1.6 trillion in assets under management, have called for enhanced environmental, social, and governance reporting, and the role climate change can play in shaping corporate value is explicitly noted (Uebelein *et al.*, 2020). At the international level, Climate Action 100+ represents another promising development, wherein a large group of investors is advocating for enhanced corporate disclosures in line with the TCFD (Climate Action 100+, 2021a). As of October 2021, this organization included 6,155 global investors representing US$55 trillion in assets under management (Climate Action 100+, 2021b).

Feltmate *et al.* (2020) propose the use of industry-specific climate risk matrices to support this kind of investor engagement. Such matrices identify the impacts of key climate risks stemming from the main climate-related hazards, along with mitigation measures and questions that can be used to determine readiness. With these matrices in hand, investors that lack specific climate-related expertise will still be well-positioned to ask the necessary questions to assess corporate understanding of and management plans relating to physical climate risks. Feltmate *et al.* (2020) identify industry associations as best placed to identify these top risks at the sector level.

Insurance policies can motivate and mandate enhanced resilience

When insurance premiums are risk-based, policy-holders receive a useful signal about the risks they face as well as financial incentives that can motivate risk reduction measures (Golnaraghi *et al.*, 2016). While this makes intuitive sense, empirical evidence on the impact of insurance pricing strategies on risk mitigation spending is lacking (Kousky, 2019). In recent decades, catastrophe models have been widely used in the insurance industry to manage large and difficult-to-predict catastrophe risks; these models "inform risk pricing and underwriting decisions, claims settlement processes, portfolio management, calculating solvency, and other regulatory, rating agency and economic capital requirements" (Golnaraghi *et al.*, 2018). Golnaraghi *et al.* (2018) flag the potential for catastrophe models to more accurately inform premium setting, clarify reinsurance needs, and ultimately enable better integration of physical climate risks into business decision-making models through the integration of up-to-date climate science and modelling. These models can also inform governments as they look to assess the benefits of a particular risk-reduction initiative (Cleary *et al.*, 2018).

A stronger form of suasion emerges when insurers establish policy eligibility requirements. This has been the case for Canadian insurers that are increasingly unwilling to insure homes with old knob-and-tube wiring (a well-recognized fire hazard), causing widespread investments in upgrades (FSCO, 2005; ESA, n.d.). In the context of climate-related property risks, some insurers are mandating the installation of backwater valves in order to qualify to hold policies covering basement flood damage (IBC, 2020b). These requirements need not only apply at the household level. In the United Kingdom, local authorities must have adequate flood defences to handle a 1-in-75-year flood in order for flood insurance to be offered to the market (Bräuninger *et al.*, 2011).

Government programs can strategically fund disaster prevention and mitigation activities

An essential element of public spending is on collective protective measures, including firefighting, seawalls, urban drainage systems, and green infrastructure. Many of the most important interventions to reduce risk need to be managed through public institutions rather than at the household level: fire suppression, fuel load management, urban drainage, and coastal defences are all examples of this. Public wildfire protection costs have run between $800 million and $1.4 billion per year over the last decade (NRCan, 2020b). Storm sewers and water treatment facilities will be under increased pressure in a changing climate, and a range of interventions will be called for, including measures to reduce runoff and expand drainage networks (Mailhot *et al.*, 2008; Groupe Agéco, 2019). An analysis of Quebec's 10 largest municipalities estimated that the additional investment in storm sewers and water treatment facilities necessitated by climate change would be $141 million to $349 million per year over the course of five years (Groupe Agéco, 2019). In British Columbia, the costs of enhancing shoreline flood protection measures along the coast of Metro Vancouver and along a stretch of the Fraser River are estimated to reach $9.5 billion by 2100 (Delcan, 2012). This study considered structural and non-structural interventions ranging from protective dikes through to planned retreat and development controls and identified what were likely to be the preferred options for distinct stretches of shoreline (Delcan, 2012). At a macro level, the Insurance Bureau of Canada and the Federation of Canadian Municipalities estimated that an annual expenditure of $5.3 billion was needed to fund adaptation and DRR across Canadian municipalities (IBC & FCM, 2020). The Municipal Natural Assets Initiative offers one path forward, seeking to harness routine asset management to finance the protection of natural assets to deliver sustainable municipal services, including stormwater management and coastal protection (MNAI, 2021).

> "Many of the most important interventions to reduce risk need to be managed through public institutions rather than at the household level: fire suppression, fuel load management, urban drainage, and coastal defences are all examples of this."

Beyond its responsibility for government-owned assets and infrastructure, the federal government plays a key role in funding and motivating prevention and mitigation investments. Infrastructure Canada's Disaster Mitigation and Adaptation Fund provides funding to large infrastructure construction projects that are expected to reduce the impacts of natural hazards and extreme weather in a changing climate (INFC, 2019a). This program runs from 2018 to 2034 with

$3.4 billion in funding (INFC, 2019a, 2020b; GC, 2021c). The Inuvik Airport received $16.5 million from this fund to pursue measures to slow permafrost thaw around the airport runway; in this instance, gradual permafrost thaw can lead to sudden damage to critical infrastructure with cascading consequences when access to a community is severely limited (INFC, 2019c). Both this fund and PS's National Disaster Mitigation Program (Section 5.1.2) focus upstream on prevention, mitigation, and preparedness. Provincial governments also disburse this type of funding. For instance, disaster mitigation expenses are eligible as part of the Government of Ontario's $1 billion COVID-19 Resilience Infrastructure Stream (Gov. of ON, 2020a).

Governments can also provide indirect support to disaster resilience by applying a climate lens to a wide range of funding programs. Infrastructure Canada requires applicants to complete a Climate Lens Assessment to access funds from the Government of Canada for projects costing over $10 million and points to the PIEVC Protocol as one methodology for supporting these assessments (INFC, 2019b). However, applicants have significant discretion in designing the assessment and choosing the level of detail to provide (Li *et al.*, 2019). This allows users to reduce the assessment to a short document produced with limited effort within the course of a few months, bypassing the value and opportunity offered by a more in-depth, multi-stakeholder process that promotes a shared understanding of climate risks and adaptation strategies, as is found in the full PIEVC Protocol (Li *et al.*, 2019). The federal government also operates as a lender and has begun to factor climate change risks into loan programs. One COVID-19 loan program offering bridge financing to large employers requires recipients to disclose climate-related risks on an annual basis (PMO, 2020).

Governments can additionally offer incentives to encourage household-level investments. In response to local fire risk, Boulder, Colorado's municipal government established the Wildfire Partners program to coach homeowners on reducing wildfire risks, to subsidize mitigation investments, and to improve home insurability (Wildfire Partners, n.d.). Community engagement and the public signalling of behaviour change through visible signals such as yard signs have been identified as important features of the program (Boulder County, 2016; Byerly *et al.*, 2020).

When it comes to selecting the most pressing areas for government disaster resilience investments, Hill and Martinez-Diaz (2020) note that beyond the aggregate expected returns, there is an important equity dimension to consider. Factoring in welfare losses can provide additional insights, as "helping a poor family prevent the loss of a dollar has larger benefits in terms of hardship and suffering avoided than does sparing a rich family the loss of that same dollar" (Hill & Martinez-Diaz, 2020).

5.2.2 Expansion of Insurance Coverage

Expanded insurance coverage could be encouraged and compelled by insurers, lenders, and governments when warranted

Although risk can be greatly reduced with proper physical and societal measures in place, residual risk remains. Thoughtfully designed insurance is an effective method of risk sharing, which is critical to building disaster resilience in a changing climate (Swiss Re, 2016). In the event that policy-holders misunderstand their coverage, simply increasing awareness of gaps in coverage could motivate greater uptake. The Organisation for Economic Co-operation and Development (OECD) surveyed member states and identified a wide range of education and awareness initiatives undertaken by governments and the insurance industry but noted that the performance of these initiatives is poorly understood (OECD, 2007).

Confronting some of the cognitive biases that limit current reliance on insurance could also drive greater uptake. Offering an annual reward for the absence of an insurance claim could counteract the tendency of homeowners to drop insurance coverage over time. These rewards can help consumers perceive not using insurance as a positive outcome rather than as evidence that they should not have purchased the policy in the first place (Meyer & Kunreuther, 2017). The option to opt out rather than in to flood insurance could be provided; evidence shows people are less likely to opt out of such an option than they are to accept what is being offered (Meyer & Kunreuther, 2017). Multi-year insurance contracts could reduce the likelihood of individuals dropping their coverage and further motivate insurers to verify that structures are being appropriately constructed and maintained (Kunreuther, 2015). Product bundling as part of mortgages is another way to encourage greater uptake (Holzheu & Turner, 2018).

Mandating various forms of disaster insurance as a condition of mortgages could also offer some protection (Meyer & Kunreuther, 2017). Research in the aftermath of Hurricane Harvey found that homeowners with existing flood insurance were less likely to delay or default on mortgage payments relative to homeowners without insurance (Kousky *et al.*, 2020). In Canada, mortgage lenders already require some forms of home insurance (IBC, 2020a); in the Panel’s view, adjusting these requirements to ensure adequate protections from climate-related hazards is increasingly warranted in the face of mounting disaster risks.

Insurance may also be compelled for other reasons, including efforts to minimize adverse selection, ensure financial viability, and enhance equity via cross-subsidization, but these efforts can run counter to risk-based price signalling (A.M. Best Company Inc., 2016). Policy-makers are pulled in competing directions, with the need to address genuine affordability challenges potentially undermining the goal of reducing exposure (Meyer & Kunreuther, 2017). Means-tested vouchers that help cover the costs of flood insurance, funded from the general tax base, are a promising approach to addressing equity concerns without undermining the price signal of the insurance program (Kousky & Kunreuther, 2014). Funding hazard mitigation through grants and loans can also play an important role in enhancing resilience (Kousky & Kunreuther, 2014).

Novel and non-traditional insurance products can help bridge current gaps in coverage

Climate change may increase some disaster risks to the extent that private insurers are no longer willing to provide coverage (PRA, 2015). Lloyds (2014) found that the damage caused by Hurricane Sandy's storm surge was 30% more costly than it would have been in the absence of the 20 centimetres of sea-level rise that Lower Manhattan had already experienced by that time. More broadly, principles of insurability may be undermined for some climate-related natural hazard risks. Uncertainty, correlated losses across multiple policy-holders and types of insurance, adverse selection, limited enrolment, and moral hazard could all reduce the willingness of private insurers to offer such coverage in the absence of public involvement (Golnaraghi *et al.*, 2016). Public–private partnerships can provide coverage in cases where the private sector deems the risk too great or in cases where affordability considerations make a fully private approach impractical (Box 5.1). These programs are already established for managing flood risks in many jurisdictions. In fact, Canada is an outlier among the many advanced economies offering some form of nationalized flood insurance (e.g., the United Kingdom, France, Spain) (A.M. Best Company Inc., 2016). A review of natural catastrophe schemes established across Europe observed the following elements of success: mature insurance systems, government-insurance sector collaboration, complementarity with private insurance offerings, controls to limit adverse selection, and financial sustainability (A.M. Best Company Inc., 2016). One noteworthy innovation in the United Kingdom's Flood Re scheme is its time-limited nature, with the program established to support a transition over the course of 25 years (Flood Re, 2018). The federal government is exploring options for a national flood insurance program (PMO, 2019a; PS, 2020b).

Box 5.1 Managing the Affordability of Flood Insurance

Encouraging broader uptake of overland flood insurance is one strategy for minimizing public expenditures on disaster relief and recovery. However, managing the affordability of flood insurance in high-risk areas is challenging, typically requiring both public and private sector involvement. Flood insurance regimes involve a fundamental tension between affordability and efficiency (IBC, 2019). If the price of coverage is too high, property owners opt out because they are unwilling or unable to purchase insurance. If the price of coverage is artificially lowered through government subsidies or regulation however, it is not proportional to the level of risk and expected losses. It thereby fails to fully incentivize appropriate flood risk reductions and jeopardizes the sustainability of coverage (IBC, 2019). Countries have taken different approaches to managing this tension, including bundling flood insurance with home insurance (Lamond & Penning-Rowsell, 2014; OECD, 2016b). This effectively prevents homeowners from opting out, allowing insurers to offer coverage at a lower cost by pooling risk.

In countries where flood insurance is optional, however, managing affordability requires different approaches. In the United States, flood insurance is optional but can be procured through the government-backed National Flood Insurance Program (NFIP) in participating communities (Kunreuther, 2015). The premiums collected under the NFIP, however, have historically been insufficient to cover the costs of insured losses, leading the program to become increasingly indebted. New legislation passed in 2012 would have required premiums more reflective of the underlying risk. These changes were met with strong resistance from homeowners, who argued that the proposed price increases were unjustified and unaffordable. After widespread opposition, subsequent legislation in 2014 scaled back the changes, instead mandating the development of a new affordability framework for the program (Kunreuther, 2015). In the absence of effective strategies for managing affordability, public opposition can prevent attempts to achieve broader insurance coverage with premiums that accurately reflect the underlying risk. One helpful innovation of the NFIP is the Community Rating System, which uses insurance premium discounts to encourage and reward municipal investments in flood management (FEMA, 2021b). In 2021, the U.S. Federal Emergency Management Agency introduced a new approach to risk rating that is intended to improve equity by better reflecting real flood risks and the costs of rebuilding; the previous approach saw lower-valued homes overpaying relative to higher-value homes, which were underpaying (FEMA, 2021a).

Parametric insurance policies, which make payouts based on thresholds such as a specific rainfall measurement, have been identified as a strategy to motivate prevention investments and have the additional benefit of being easier to administer than standard indemnity-based policies that are issued based on observed losses (Bräuninger *et al.*, 2011). For instance, a policy could specify a wind speed threshold that would trigger a pre-determined payout for a hurricane irrespective of the damages actually incurred (Swiss Re, 2020). Catastrophe bonds could also improve resilience by transferring risks from the public sector to financial markets (Kovacs *et al.*, 2021).

5.2.3 Building Forward Better in Recovery

Improving understanding of the value of resilience investments going forward could encourage greater uptake

Building forward better is emphasized as an opportunity to make the most of recovery efforts by reducing future risks while simultaneously rebuilding from previous disasters (MREM, 2017). The Panel opted to use the expression *building forward better* rather than the more widely used *building back better* to underscore the need to build differently for a changing climate. Although the economics of adaptation investments can be difficult to assess, generally speaking, the cost of building something that is designed for the future climate from the outset is lower than that of retrofitting existing structures (UNISDR, 2011; Carlson *et al.*, 2021; Kovacs *et al.*, 2021). When it comes to infrastructure, building forward better means designing to withstand anticipated, emerging climate shifts that will change the operating environment conditions for an asset within the life of its expected duty (Swiss Re & GIF, 2021). However, constraints in public procurement processes that favour the lowest bid can make it difficult to operationalize this approach (AAPPQ, 2018; PWGSC, 2020).

Public funding programs could be amended to enable building forward better

The Disaster Financial Assistance Arrangements program allows disaster mitigation investments as part of repair and rebuilding: up to 15% of the full expected cost of bringing an asset back to its pre-disaster level (PS, 2007). There have been very few requests for mitigation funding from provinces and territories (PS, 2017a), suggesting that more action is required to incentivize the uptake of this element of the program. Moving forward, the federal government intends to develop a plan to facilitate relocation for homeowners in the areas facing the greatest flood risks and has convened a task force to work through options (PMO, 2019a; PS, 2020b).

This is already underway in the United States, with the Army Corps of Engineers requiring relocation as a condition for federal flood protection funds in some circumstances (Flavelle, 2020). This reflects their conclusion that paying for relocation is, in some cases, less expensive than maintaining adequate flood defences (Flavelle, 2020). The U.S. Department of Housing and Urban Development is offering several billions of dollars in funding to support disaster mitigation, including through property buy-outs (HUD, 2019, 2021).

5.3 Capabilities

5.3.1 Catastrophe Modelling

Catastrophe models (Cat models) emerged in the insurance sector in the 1980s as a tool to improve understanding of the risks of large and unpredictable losses (Golnaraghi *et al.*, 2018). These models are built from information about hazards, exposure, vulnerability, and monetization of losses, and have the potential to offer better disaster risk insights through the incorporation of climate projections. As Cat models develop more sophisticated linkages to the most up-to-date global climate models, they will become a more powerful tool for risk mitigation and transfer. Golnaraghi *et al.* (2018) also point to Cat models as a tool to address the recommendations of the TCFD to better incorporate climate risks in investment choices. These models could also shed further light on poorly understood interdependencies and the cascading effects of hazards, as well as the potential for critical infrastructure failures. Developments that could advance the reliability and impacts of Cat models include improved interoperability and standardization, open-access formats, enhanced model valuation and management of uncertainty, and closer attention to resourcing needs (Golnaraghi *et al.*, 2018).

5.3.2 Choice Architecture

Cognitive biases can impede efforts to build resilience (Section 2.3.2). Recognizing that decisions are partially a function of the way in which choices are presented, Thaler and Sunstein (2008) proposed the concept of choice architecture, which refers to "organizing the context in which people make decisions." This concept can be employed to motivate disaster resilience investments at the individual and institutional levels. In their research on behavioural economics and disaster risks, Meyer and Kunreuther (2017) remark on the vast array of biases that come together to create "a perfect storm of potential decision errors," but note that few policy interventions seem to be designed with these biases in mind. The authors advocate that policy-makers undertake behavioural risk audits to identify relevant biases, how they impact beliefs, how these beliefs may manifest themselves in behaviours, and potential policy remedies. For instance, making flood insurance part of a default home insurance package could accommodate the role that inertia (i.e., the tendency to default to the status quo) plays in shaping decisions (Meyer & Kunreuther, 2017). Capacity for this kind of work is growing (OECD, 2017b). Public sector attention to choice architecture originated in the United Kingdom's Behavioural Insights Team and has spread to many other countries (OECD, 2017b). The Government of Canada established its Central Innovation Hub in 2015, and similar initiatives exist at the provincial level through groups such as British Columbia's Behavioural Insights Group and Ontario's Behavioural Insights Unit (IOG, 2018; Gov. of ON, 2020b; Gov. of BC, n.d.-a).

5.3.3 Financial Disclosure

The Expert Panel on Sustainable Finance reported multiple barriers to implementing the TCFD recommendations in Canada, including "cost and capacity of smaller issuers to adopt [and] lack of knowledge support in the professional ecosystem" (GC, 2019c). The Canadian Securities Administrators have begun to advise on these disclosures, offering questions that can be used by boards and management to prepare disclosures and guidance on determining materiality (CSA, 2019). This enhanced guidance was prompted in part by the Canadian Securities Administrators' review of the disclosures of a sample of 78 TSX-listed companies, which revealed weak and incomparable disclosures across many firms (CSA, 2019). The TCFD has also developed guidance on integrating climate-related risks in existing risk management processes, alongside advice and examples for including these risks in disclosures (TCFD, 2020). Scenario-based analysis offers a valuable tool for exploring the possible financial consequences of disasters in a changing climate (Bolton *et al.*, 2020).

5.4 Key Opportunities for Integration

Insurance policies, funding programs, and investment choices can all contribute to the successful integration of DRR and adaptation. Insurance eligibility requirements and coverage mandates can encourage policy-holders to take action to mitigate disaster risks and provide greater financial stability when disasters do unfold, which could become increasingly beneficial in a changing climate. Applying a climate lens to infrastructure funding programs can support the development of infrastructure that will be more resilient to extreme weather in the future. Government relief programs that incentivize recipients to rebuild in more resilient ways and locations can reduce the potential future payouts for these programs. Ultimately, recognizing the value of mitigation investments and shifting spending upstream will help minimize losses in a changing climate.

6

Operationalizing Integration of DRR and Adaptation

6.1 Building Effective Coalitions for Enhancing Disaster Resilience

6.2 Compelling Action to Improve Disaster Resilience

6.3 Key Opportunities for Operationalizing Integration

Chapter Findings

- A collaborative whole-of-society approach to decision-making offers the long-term perspective necessary to advance DRR in a changing climate. Additionally, whole-of-society approaches are successful in securing legitimate and durable policy outcomes. This collaborative and participatory style of governance facilitates the integration of adaptation and DRR to enhance disaster resilience for all.
- Local governments and Indigenous communities are best placed to identify local vulnerabilities and implement the most appropriate actions for realizing the integration of DRR and climate change adaptation. Higher orders of government offer critical support by providing knowledge, financing, regional coordination, and capacity building at the local level.
- Recognizing the capacities and capabilities of Indigenous communities and supporting self-governance reduces jurisdictional conflicts and enhances community resilience to natural hazards.
- Sufficient and widespread focus on disaster prevention and mitigation will only come about when governments mandate it. Requiring adherence to codes and standards that incorporate climate change adaptation is an important step for reducing the vulnerability of the built environment to future hazards.

The actions required to enhance disaster resilience in a changing climate are well understood (Chapter 3), as are the enabling roles of information, financing, and insurance (Chapters 4 and 5). Ultimately, however, leadership, role clarity, and accountability are necessary to bring about the integration of DRR and adaptation practices. These actions need to be assigned to a responsible party that has adequate capacity to fulfill its role.

Improving disaster resilience in a changing climate requires engagement from all levels of society, including individuals, the private sector, and governments operating at all levels. The Panel observes that top-down decision-making alone is not fit-for-purpose to increase disaster resilience. No one group has all the money, knowledge, or authority needed to centrally coordinate this charge. Figure 6.1 presents the groups identified throughout this report working on DRR and adaptation. This conceptual map highlights the volume, range, and operating scales of these actors, who are additionally connected to health, economic development, environmental management, security, and other aspects of resilience. There are no clear — or even desirable — boundaries to be drawn around this diverse group of actors; confronting the inevitable governance and coordination challenges associated with such a complex landscape will be critical to making progress. This chapter identifies how whole-of-society approaches can play an important role in DRR and adaptation and offer strategies to motivate action and create accountability.

> "No one group has all the money, knowledge, or authority needed to centrally coordinate this charge."

6.1 Building Effective Coalitions for Enhancing Disaster Resilience

This section explores the various ways effective coalitions can enhance disaster resilience. This includes whole-of-society approaches, Indigenous self-governance, local leadership, and inter- and intra-organizational collaboration.

6.1.1 Whole-of-Society Approaches

Prevention, mitigation, preparedness, and recovery planning benefit from whole-of-society engagement

The inherent complexity and wide-reaching effects of both DRR and adaptation necessitate a flexible and diverse approach to the management of risks in a changing climate. In the Panel's experience, highly structured command-and-control decision-making can be an effective strategy for minimizing confusion and ensuring rapid response during an emergency. However, the inherently longer-term nature of adaptation activities — as well as prevention, mitigation, preparedness, and recovery within DRR — lend themselves to a more collaborative and participatory style of decision-making. Whole-of-society approaches promote the participation of many stakeholders in decision-making processes to ensure a balanced and representative mix of individuals and groups (Hewitt *et al.*, 2017). Incorporating a diverse range of perspectives and ensuring that interactions are respectful and that everyone's opinions are heard and valued are key tenets of a whole-of-society approach (Hewitt *et al.*, 2017). Indeed, "[c]ollaboration that is inclusive, transparent, and incorporates diverse perspectives, from the initial planning phases right through to adaptation implementation, enhances outcomes for all" (Brown *et al.*, 2021).

As illustrated in Figure 6.1, DRR and adaptation implicate a wide range of stakeholders, including individuals; homeowners and renters; governments; Indigenous communities and organizations; emergency response organizations; and professionals, such as planners, developers, builders, engineers, academics, and actors in real estate. Non-governmental organizations (NGOs), philanthropic organizations, and the private sector also play important roles in risk reduction and adaptation (Delica-Willison *et al.*, 2017). For example, a partnership between the World Wildlife Fund and the insurer RSA Canada is collaborating with local communities to advance adaptation planning and establish natural infrastructure while simultaneously re-establishing ecosystem function in the St. John watershed (RSA Canada, 2021).

The importance of whole-of-society approaches to building disaster resilience is well-recognized and has been highlighted as a component of decision-making in infrastructure resilience, sustainable development, adaptation, and DRR (UNISDR, 2015; UNCCS, 2017; GC, 2019b; Brown *et al.*, 2021; IISD, 2021). The UN Sustainable Development Goals reference participatory and inclusive planning and decision-making (Goals 11 and 16) and, the Sendai Framework also explicitly discusses the inclusion of multiple stakeholders in strategies to reduce risk while simultaneously drawing attention to the importance of regulation and coordination from higher orders of government (UN, 2015; UNISDR, 2015). In step with the international community, FPT governments have recognized the importance of a whole-of-society approach and an emphasis on resilience for the success of DRR (UNISDR, 2015; MREM, 2017). This approach is intended to foster DRR efforts that are collaborative, inclusive, and accessible, paying particular attention to the groups disproportionately impacted by disasters (UNISDR, 2015).

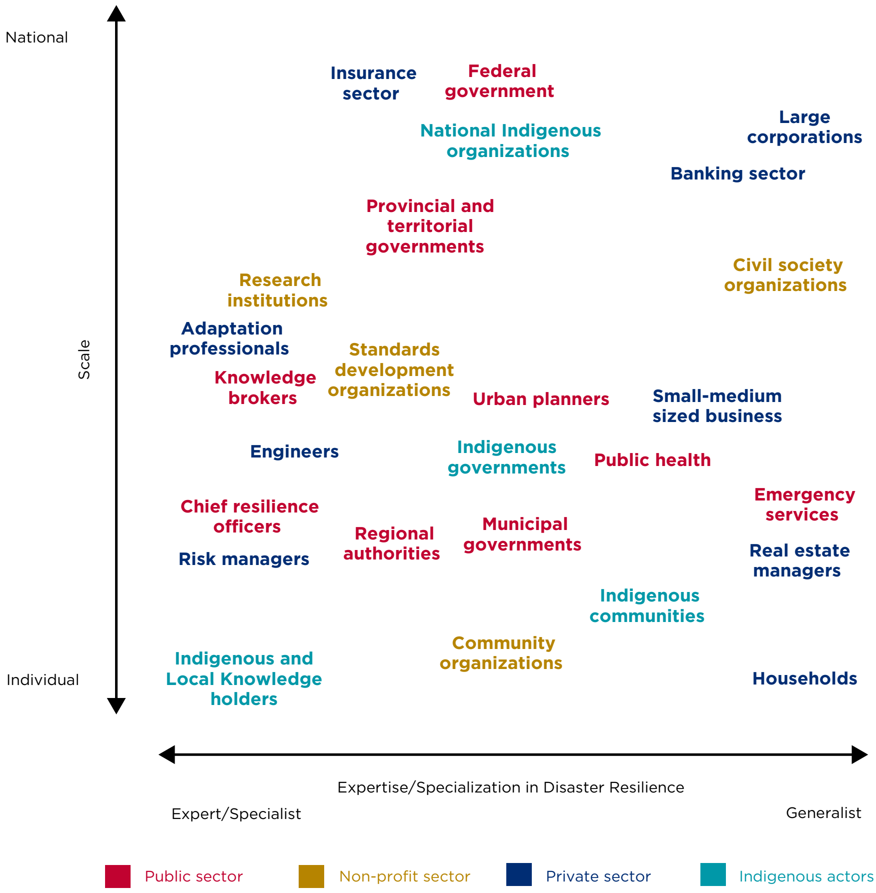


Figure 6.1 The DRR and Climate Change Adaptation Landscape

The DRR and adaptation landscape is comprised of numerous actors operating at a variety of scales and expertise levels. These actors occupy the public, private, and non-profit sectors, and they all have a role to play in strengthening disaster resilience. Although this figure presents a number of actors, it is not exhaustive and, furthermore, there may be crossover between the various sectors for certain groups.

While building inclusive partnerships can be challenging, the rewards include more enduring and widely accepted outcomes

The involvement of multiple stakeholders in decision-making processes is not without challenges. Inclusive and participatory processes often take longer than top-down approaches (Hewitt *et al.*, 2017), and defining problems, designing measures of success, and reconciling diverse perspectives and interests can all be substantive challenges for collaborative processes (Waardenburg *et al.*, 2020). Additionally, shifting away from centralized governance can pose significant accountability problems (Koliba *et al.*, 2011). If many actors are involved in decision-making, it becomes more complex to consider who is accountable and to whom (Bryson *et al.*, 2006).

Despite these disadvantages, decisions made through whole-of-society approaches pay off by achieving greater acceptance and increased legitimacy while producing more durable policy options (Hewitt *et al.*, 2017; Worte, 2017). By helping to create and implement plans and policies, stakeholders have an increased sense of ownership for these decisions (Worte, 2017). Furthermore, whole-of-society governance provides an opportunity to incorporate the perspectives of those disproportionally affected by disasters and provides a greater avenue for representing their interests (UNISDR, 2015; Gaskin *et al.*, 2017; Craig *et al.*, 2019). For example, certain populations, such as people with disabilities, older individuals, and immigrants, are more vulnerable to heat waves; ensuring equitable adaptation policies necessitates the involvement of these and other vulnerable groups in decision-making (City of Montréal, 2015; Santé Montréal, 2019; Spannagel, 2021). At the project level, local engagement, the involvement of planners and developers, and capacity building can all contribute to success (Taylor & Birkland, 2019).

Examples of whole-of-society governance approaches can be found in Canada and abroad. Emergency Management Victoria (Australia) is legislated to develop and oversee emergency management activities to effectively meet community needs (EMV, 2018). They are moving away from command-and-control systems towards a more holistic model that emphasizes community connection, capability, and capacity. Integral to this approach is the recognition that resilience requires adaptive measures to be enacted before an emergency happens (EMV, 2017, 2018). Extensive community collaboration has resulted in an inclusive governance process that seeks to incorporate both top-down and bottom-up approaches (EMV, 2018). In Rotterdam, Netherlands, the construction of a flood-control dike included extensive consultation with citizens throughout the planning and construction process, as well as partnerships among the municipal government, the project developer, and an NGO to help facilitate communication (Mees & Driessen, 2019). This partnership resulted in the creation of a park on top of the dike, with citizens participating heavily in the design process (Mees & Driessen, 2019). Watershed stewardship groups in Saskatchewan act as a forum for multiple stakeholders to discuss and collaboratively create tailored solutions for location-specific water concerns (Sauchyn *et al.*, 2020). These groups involve municipal governments, local industries, and NGOs concerned with environmental issues within a given region or watershed, all of whom participate in the design of action plans to deal with water quality, droughts, and floods (Sauchyn *et al.*, 2020).

Despite being widely viewed as both useful and politically feasible policy tools for enhancing resilience, whole-of-society tools such as stakeholder engagement and participation are still underutilized (Henstra & Thistlethwaite, 2017). Municipalities have cited a lack of capacity and adequate resources to properly undertake the time-consuming process of engagement, as well as low interest among stakeholders in outreach activities (Henstra *et al.*, 2020). In these situations, incentives from FPT governments can help to facilitate stakeholder engagement. In the case of the rooftop park in Rotterdam, the national government agreed to subsidize the project if the municipality and project developer involved local citizens in the project (Mees & Driessen, 2019). Boundary organizations and NGOs can additionally help to identify and bring together relevant stakeholders (Bednar *et al.*, 2019).

Public risk awareness and engagement can help individuals and communities take action to contribute to resilience

Public awareness and engagement about existing risks can help all actors in society take action to contribute to resilience (MREM, 2017). Individuals and communities can make significant strides to reduce their personal and property risks, and by doing so, reduce the vulnerability of communities overall. Neighbourhood and community groups can be set up to raise the profile of local risks, including vulnerability to climate-related hazards. For example, CREW, an organization in Toronto, was formed in response to extreme weather events in 2013 and involves a network of volunteers in many communities across the city. The goal of CREW is to optimize resources and provide resilience information, models, and toolkits to help communities prepare for extreme weather events (CREW, n.d.-b). CREW's Extreme Weather Volunteer Program has built up volunteer teams for emergency aid and facilitated workshops, asset mapping, and training sessions with the goal of building local leadership capacity and enhancing resilience (CREW, n.d.-a). In the United States, the Community Emergency Response Team program recruits and educates volunteers on basic disaster preparedness and response (Ready, 2021). Beyond their work in emergencies, Community Emergency Response Teams have been found to help build community capacity to respond to disasters, as well as to enhance local connections and well-being (Flint & Stevenson, 2010). Municipalities can support these initiatives by providing guidance and funding; the City of Vancouver's Resilient Neighbourhoods Program has provided small bursaries and developed a toolkit to guide community-based organizations in the creation of neighbourhood resilience teams, as well as to assess community resilience and prepare for disasters (City of Vancouver, n.d.-c).

Outreach events and meetings are also avenues for community voices to be heard by those making decisions. The Northwest Territories Association of Communities organized a multi-stakeholder forum on climate change, bringing together 166 attendees from across the Northwest Territories with representation from 25 out of 33 communities (FCM, 2021). Representatives included Indigenous communities, as well as territorial and federal governments alongside NGOs, technical experts, researchers, funders, and catalyst organizations who support community development. This meeting allowed communities to directly engage with multiple orders of government and exchange up-to-date climate change information with researchers. These discussions resulted in a climate change strategy and action plan, along with several new projects and communication tools that may have been out of reach for many communities with limited staff and resources to work on adaptation (FCM, 2021).

Another tangible example of successful community involvement comes from Seattle in the wake of the 2001 earthquake (Kelman, 2020). After a major earthquake in 1949, the city began developing a culture of readiness — in 1971, Seattle started offering free CPR lessons, resulting in early bystander interventions to save lives. In 1997, the city joined Project Impact, a federal initiative to involve residents and businesses in hazard preparedness. This program funded locally led activities to drive down vulnerability, and it was used to incentivize earthquake retrofits for homeowners and to upgrade public infrastructure. By encouraging public–private partnerships and putting responsibility in the hands of locals, this initiative was a major factor in the resilience of Seattle's residents and built environment during the 2001 earthquake (Kelman, 2020).

6.1.2 Indigenous Self-Governance

Promoting Indigenous self-governance reduces jurisdictional conflicts and enhances community resilience to natural hazards

Jurisdictional conflicts and confusion can complicate DRR in Indigenous communities (Section 2.1.2), and disaster response that does not consider self-determination in its implementation can cause further trauma and marginalization among Indigenous groups (Yumagulova *et al.*, 2019). This has led to increased vulnerability and confusion during and after a disaster (Verhaeghe *et al.*, 2019). The 2017 fire season in British Columbia was devastating for many First Nations communities (Abbott & Chapman, 2018). In the case of the Tsilhqot'in Nation, 760,000 hectares of territory was razed by fires, and three of six Tsilhqot'in communities were overtaken (Stacey, 2019). This particular case exemplifies the potential for confusion and conflict over legal jurisdiction during the wildfire response (Stacey, 2019; Verhaeghe *et al.*, 2019). For example, the Tl'etinqox community had developed comprehensive emergency plans reflective of their traditional governance structures as a result of several previous culturally inappropriate evacuations (Verhaeghe *et al.*, 2019). When the fire hit, they chose not to evacuate based on these emergency protocols (Verhaeghe *et al.*, 2019). Even though provincially mandated evacuation orders do not apply on reserve, government authorities threatened to remove the community's children if they did not comply (Stacey, 2019; Verhaeghe *et al.*, 2019).

To avoid repeating situations such as those discussed above and to reduce vulnerability to future hazards, there is a need to recognize Indigenous legal systems (Stacey, 2019). The Tsilhqot'in Nation has been a leader in this space: in 2014, Canadian courts recognized Aboriginal title for the first time, identifying the Tsilhqot'in Nation as the rightful owners of the land under Canadian law (Supreme Court of Canada, 2014). The work of the national Indigenous organizations in Canada supports self-determination in advancing resilience:

- The Assembly of First Nations is actively developing a First Nations Emergency Strategy in recognition of the need for Indigenous leadership and culture in disaster risk prevention and resilience (AFN, 2017).
- Inuit Tapiriit Kanatami developed a climate change strategy that recognizes the rights and contributions of Inuit to climate action in the North, with explicit guidance on how partners can collaborate through existing governance structures (ITK, 2019).
- The Métis National Council is pursuing self-government agreements to advance self-determination and is seeking partnerships and funding to ensure the engagement of Métis communities in emergency management and addressing climate change (MNC, 2019, 2021).

These and other initiatives, frameworks, and research programs demonstrate the vital role that these organizations play in supporting local Indigenous leadership and capacity building for resilience.

The importance of supporting the self-determination of Indigenous groups cannot be overstated. As described by Yumagulova *et al.* (2021), "building resilience in Indigenous communities in the face of climate change is fundamentally about creating opportunities for self-determination and self-sufficiency." For example, support for community organizations coordinated and operated by Indigenous Peoples can foster culturally safe recovery and ensure that the needs of the most vulnerable are met. Organizations such as the Dancing

Deer Disaster Recovery Centre, run by the Siksika Nation, delivered services to displaced First Nations in the wake of extensive flooding in 2013 to address physical, mental, and social well-being (Yellow Old Woman-Munro *et al.*, 2021).

To create meaningful and inclusive partnerships, Indigenous participation needs to be embedded and supported from the start of all decision-making processes, including those related to disaster resilience

Top-down approaches for adaptation and DRR are often unsuccessful when they fail to consider local needs and the potential for integrating Indigenous resources and capacities is ignored (Delica-Willison *et al.*, 2017; Abbott & Chapman, 2018; Verhaeghe *et al.*, 2019). For example, wildfires have resulted in frequent evacuations, which in turn cause social disruptions, community fragmentation, physical and mental health concerns, and economic difficulties (Sankey, 2018). Interviewees from the 2018 House of Commons report on *Fire Safety and Emergency Management in Indigenous Communities* pointed out that the social and cultural impacts of evacuation can be much greater than the impact of the actual emergency, especially if trauma counselling is inadequate (HoC, 2018). Indigenous groups understand their own needs and are best placed to coordinate and direct local responses to disasters (HoC, 2018). Murphy *et al.* (2017) provide the following example of a successful initiative to mitigate some of these negative effects:

> *Tobique First Nation, NB [New Brunswick], has developed the Wampum Critical Incident Stress Management (CISM) Network. It is now shared across several Maliseet communities. The Network was developed by an Elder and residential school survivor who recognized that there were unmet mental health needs during and after crises including suicides and disasters. All individuals are trained in CISM protocols that are adapted to Indigenous ways of knowing. For instance, when an incident occurs, a smudging or other ceremony may be performed. Perhaps a sacred fire will be lit where people can gather and team members attend as a compassionate presence. With several teams now in place, the teams can be invited in to respond to another's crises. This is key for the impacted community whose Network members may also be affected by the incident.*

Community-based DRR plans build on ILK and capabilities and can clearly define the role of external actors in an appropriate and complementary way. Respectful communication, including training, education, and relationship-building activities, needs to be ongoing and extend beyond the typical disaster seasons (Verhaeghe *et al.*, 2019). Engaging in annual table-top exercises for a variety of disaster response scenarios with all relevant community and emergency response participants has also been suggested to improve communication and test plan viability (Abbott & Chapman, 2018). Novel DRR or mutual aid agreements are a step in this direction. In 2018, the Tsilhqot'in Nation, the federal government, and the Government of British Columbia entered into a collaborative emergency management agreement aiming to build effective partnerships and avoid a repetition of the 2017 fire season events (Tsilhqot'in National Government *et al.*, 2018). A collection of recommendations was then produced by Tsilhqot'in Nation to "support Indigenous peoples as true partners, experts, and government authorities in emergency management" (Verhaeghe *et al.*, 2019). This is just the first step, however; detailed and community-specific agreements will need to be negotiated to ensure agreement on roles and responsibilities for all aspects of DRR (Verhaeghe *et al.*, 2019).

DRR and adaptation plans developed within communities by trusted local residents also tend to be more highly accepted and implemented. At the Peavine Métis Settlement in Alberta, Christianson *et al.* (2014) found that when cultural values were incorporated into the wildfire mitigation program, there was a higher level of acceptance. The forestry coordinator who developed the plan was a member of the community, and their process made sure to include specific considerations for Elders and recreational areas in the plan, reflecting community values and resulting in widespread community support (Christianson *et al.*, 2014). The process of creating plans promotes a sense of ownership and empowerment and can elicit community support while reducing risks (Clark, 2017). Although much of the work being done is around preparedness and response to hazards, these strategies can be applied to prevention, mitigation, and recovery as well. Communities that are empowered to make their own decisions can also take actions to prevent disasters from occurring in the first place, as in the case of Indigenous fire management (Section 3.1).

6.1.3 Local Leadership

Many risks are best managed at local and community scales, but municipalities often lack the authority and resources to act

Impacts from natural hazards most often manifest at a local scale, which can refer to communities, neighbourhoods, or municipalities. Local public officials generally hold the greatest awareness of issues impacting their constituencies and can assess the potential of various solutions for addressing them (Juillet, 2013).

While local communities and municipalities may be best positioned to assess and understand their own risks and vulnerabilities, they often lack the mandate, resources, and political will to enact changes (Brown *et al.*, 2021). Municipal authorities and the scope of their powers depend on what is granted by provinces and territories (Juillet, 2013). For example, cities that have designated floodplains note that their designation is based on provincially established standards, and any changes proposed by municipalities must be passed through the provincial legislature first (Feltmate & Moudrak, 2021). In addition, although they are at the forefront of disaster responses, municipalities have the weakest fiscal capacities compared to all other orders of government. Their heavy reliance on property taxes (rather than sales or income taxes) creates a pro-development incentive (Henstra, 2013). Municipal councils, which hold the greatest responsibility for land-use restrictions, can override their own bylaws to approve rebuilding or new development in areas that are recognized as hazard-prone (Feltmate & Moudrak, 2016; Keller & McClearn, 2020). Additional pressures come from influential stakeholder groups such as homeowner associations, lobbyists, and property developers who have resisted measures such as regulating development and making more space for natural processes when they interfere with development plans (Bogdan *et al.*, 2020). A survey-based study on adaptation initiatives around the Bay of Fundy in Nova Scotia found that "limited staff time and expertise, stretched budgets, and lack of jurisdictional authority" acted as barriers to addressing climate change-related vulnerabilities (Shauffler, 2014). These barriers are exacerbated for smaller municipalities that lack the same resources as some larger cities (Raikes & McBean, 2017).

Higher orders of government can support local progress by offering resources and a coordinated direction

Building adaptive capacity in local governments can be achieved through the provision of social, technical, and financial support by higher orders of government (Rutledge, 2017; UNCCS, 2017; Albright, 2019). Many municipalities do not have the capacity to produce high-quality flood hazard maps adequate for local decision-making; it has been suggested that more senior levels of government assist municipalities by providing detailed and up-to-date flood hazard information (Stevens & Hanschka, 2014). In Nova Scotia, the provincial government mandated that municipalities had to complete adaptation plans to access funds for infrastructure projects (Vogel *et al.*, 2020). Municipalities were aided through capacity-building support that included workshops, webinars, and participatory adaptation research projects, along with a guidebook containing baseline scientific information to act as a starting point for plans before customization (Vogel *et al.*, 2020). This support was viewed as instrumental to the success of the initiative, and to date, 75% of coastal adaptation actions identified through this program are either in progress or complete (Righter, 2021).

Coordinating and operating measures for reducing the risks of regional infrastructure failures is another important role for higher orders of government. Large urban centres such as Vancouver depend on an intricate and interdependent system of infrastructure, so in the event of a major disaster, there could be cascading failures within critical systems such as power generation, water, and healthcare (Chang *et al.*, 2019a).

In the Netherlands, the Room for the River initiative offers another model of involvement for central governments. The initiative was launched in 2006 to create more space for rivers when the discharge of water from upstream became greater than previously accounted for (Rijke *et al.*, 2012). This project used a novel mix of governance structures, which included centralized support with decentralized decision-making (Rijke *et al.*, 2012). The national government established a central program office to provide support for regional project teams and to track progress (Zevenbergena *et al.*, 2015). For example, the program office acted as a base of expert knowledge to be drawn upon by regional project teams when specific expertise was required; if the relevant advice was missing, guidance on where to find it was provided (Rijke *et al.*, 2012). The program office would also provide guides and handbooks for common issues to save time and effort (e.g., for conducting risk assessments, placement of underground cables). Finally, should existing policy and legislation stymy project progress, the program office could convene national policy-makers and legislators to update or change laws. This system allowed for regional and local offices to retain control of the design, planning, and implementation of river modifications with the support of the national government (Rijke *et al.*, 2012).

In the Panel's view, a blend of governance approaches is necessary for enhancing resilience to future disasters and climate change in Canada. While local leadership is critical for creating and implementing suitable DRR and adaptation actions, FPT governments also play a crucial role by providing an overarching policy direction, ensuring regional cohesiveness, and enacting legislation to prompt local governments to make progress on resilience (Oulahen *et al.*, 2018). This combination of governance approaches has been repeatedly recognized in various IPCC reports as required for integrating adaptation into sustainable land and coastal management, specifically citing "the advantages of centralised governance (with coordination, stability, compliance) with those of more horizontal structures (that allow flexibility, autonomy for local decision-making, multistakeholder engagement, co-management)" (Hurlbert *et al.*, 2019). The importance of local decision-making is also recognized in the Sendai Framework, which emphasizes the necessity of empowering local authorities and communities to address their own risks through the provision of resources and regulations (UNISDR, 2015).

6.1.4 Bridging Silos

Organizations and partnerships operating at a regional scale offer opportunities for resource sharing and coordinated regional planning

Natural hazards are not bound by political boundaries and frequently cross them to encompass a greater area than is controlled by one political entity (Albright, 2019). Jurisdictions must therefore be prepared to collaborate and communicate effectively with neighbours and other levels of government. For example, large wildfires can quickly overwhelm staff in Indigenous communities and exceed emergency management equipment and supplies, making collaboration with nearby communities on planning and preparedness crucial (FireSmart Canada, 2020).

This can take the form of mutual aid and service agreements, where resource requirements and services can be shared among Indigenous communities. They can also potentially involve nearby municipalities, emergency response organizations, and even private companies (Murphy *et al.*, 2017). These agreements encourage a bottom-up approach to governance and planning where regions can collectively organize resources. They can also involve joint requests for upgrading critical infrastructure, addressing regional flooding or fire risks, joint training, sharing the employment cost for a regional emergency management coordinator, coordinating evacuation and education plans, and planning for cooperative reconstruction and repair (Murphy *et al.*, 2017).

The unique system of conservation authorities in Ontario has been cited as a successful way of managing flood risk for an entire watershed (as summarized by Shrubsole *et al.* (2003)). Conservation authorities are empowered to develop flood maps and restrict development in high-risk areas and were highly successful in facilitating widespread retreat in the wake of Hurricane Hazel (Henstra & Thistlethwaite, 2017; Kelman, 2020). Conservation authorities reflect a whole-of-society approach, effectively engaging a variety of stakeholders and enabling discourse and problem-solving among governments and other stakeholders (Mitchell *et al.*, 2014). This success has been attributed to a "collective mandate with measurable objectives, articulated roles and responsibilities for all participants, capacity to obtain financial and human resources, and capacity to influence initiatives with implications for water security" (Pentland and Wood (2013) as cited in Mitchell *et al.* (2014)). This system has been recognized internationally, with two conservation authorities (Grand River and Simcoe Lake Region) receiving the Thiess International Riverprize (Mitchell *et al.*, 2014; IRF, 2021a, 2021b).

The Okanagan Basin Water Board, another example of a regional organization, was established by the Legislative Assembly of British Columbia in 1970 to manage critical water concerns at the watershed scale (OBWB, 2021a). Issues are considered jointly by three regional districts: the Okanagan Nation Alliance (comprised of eight First Nation communities), the Water Supply Association of BC, and the Okanagan Water Stewardship Council (a stakeholder group that provides independent science-based advice on water issues) (OBWB, 2021a). The Okanagan Basin Water Board supports multiple projects, including floodplain mapping, hydrologic modelling, analysis of flood policy and planning tools, and groundwater monitoring (OBWB, 2021b).

North Shore Emergency Management in Vancouver is using a coordinated regional approach to create a comprehensive adaptation plan for sea-level rise (KWL, 2020). Key activities include flood mapping and risk assessment, and the overall project objective is to "foster an understanding of the sea-level rise risk across the North Shore, to establish a coordinated set of action areas to manage the risk and, ultimately, to build adaptability and resilience to sea level rise in all three North Shore municipalities, Squamish Nation, and the Port Authority" (KWL, 2020). Another successful example of regional partnerships in British Columbia is the Fraser Basin Council, which has been developing the Lower Mainland Flood Management Strategy (FBC, n.d.). This strategy is a collaborative initiative among the federal and provincial governments, Lower Mainland local governments, First Nations, NGOs, and the private sector (FBC, n.d.). The collaborative nature of the Lower Mainland Flood Management Strategy allows participants to come together to share information, work to fill knowledge gaps, build consensus on flood management strategies, and share costs (FBC, n.d.).

Pre-existing regional partnerships can save time and effort by serving as the governance body for new climate-adapted DRR initiatives. Irrigation districts in the Prairie provinces are one such example: they were developed to manage local water for irrigation but are now involved in participatory scenario exercises to prepare for droughts as well as excess moisture events (Sauchyn *et al.*, 2020). It has been suggested that organizations such as the Prairie Provinces Water Board be repurposed with a greater mandate to coordinate a regional approach to flood risk management, while still recognizing an overarching policy vision from the federal government (Morrison *et al.*, 2018).

Individuals or groups focusing on resilience can break down institutional silos and drive resilience activities at local and regional levels

Currently, roles and responsibilities for certain aspects of adaptation and DRR remain unclear both within and among orders of government, and there is the potential for jurisdictional gaps or overlaps. For example, a study by Morrison *et al.* (2018) on the Prairie provinces found that holistic flood risk management involves several different policy areas that are housed within different departments. A lack of coordinating strategies or actors specifically responsible for flood risk management resulted in mismatched policies and difficulty going beyond standard preparedness and response activities (Morrison *et al.*, 2018). For this study of flood risk management, actors at all three orders of government as well as academics, NGOs, and other stakeholders were interviewed. The study found that the responsibility for coordinating action was rarely assigned to any order of government (Morrison *et al.*, 2018). Another study of multi-level governance for adaptation in British Columbia had similar conclusions and additionally noted that within the province, "no single ministry has the mandate to take a leadership and coordination role, which creates ambiguity about who is accountable and how to coordinate decision-making" (Oulahen *et al.*, 2018).

"Resilience strategies do not only address adaptation and DRR, they also often recognize equity as a key component of resilient futures."

These impediments can be addressed through the appointment of individuals or creation of offices whose job is to drive resilience efforts within an entire city or region. Individuals such as chief resilience officers can link up capabilities by connecting governments, academics, and professionals and developing a common language for resilience that can be understood by all parties involved (Hill & Martinez-Diaz, 2020). The role of the chief resilience officer was originally created and funded through the Rockefeller Foundation's 100 Resilient Cities initiative, and is currently supported by the Resilient Cities Network (RCN, 2021). The position is intended to coordinate a city's resilience efforts and facilitate collaboration among internal departments as well as with communities and other stakeholders (Berkowitz, 2014). The Resilient Cities Network is comprised of 97 of the former participants in the 100 Resilient Cities program, of which 83 have institutionalized chief resilience officers. As of 2018, this initiative has led to the release of 40 city resilience strategies, many of which are being implemented (Martin-Moreau & Ménascé, 2018). Other cities have created entire offices to deal with resilience planning, as is the case with Montréal's Office of Ecological Transition and Resilience (Cloutier *et al.*, 2020). This office supports the ongoing implementation of Montréal's resilience strategy and coordinates with other operational units to advance work in GHG emission reduction, social capital, carbon neutrality, adaptation, and the protection of the natural environment (Cloutier *et al.*, 2020).

Resilience strategies do not only address adaptation and DRR, they also often recognize equity as a key component of resilient futures. In the process of creating Toronto's Resilience Strategy, public consultations highlighted that "things like a lack of affordable and stable housing, a lack of reliable transit, concern about community safety and loss of life, and discrimination in finding employment" all affected citizens' capacity to be resilient (City of Toronto, 2019). Actions such as providing affordable housing to marginalized and underserved populations reduce vulnerability and exposure to hazards and work to enhance the resilience of these populations. Additionally, housing designed and constructed to withstand a variety of conditions expected in a changing climate will be most effective at protecting citizens who need it most (RNPN *et al.*, 2021).

The inclusion of land-use planners in DRR efforts can promote long-term thinking and provide a clear place for the integration of adaptation

In shifting the focus of governments and DRR actors towards preparedness and mitigation, there is a significant role to be played by land-use and transportation planners, designers, and engineers (Marten *et al.*, 2019; Schwab, 2019). Growing populations, increasing demand for space, and shifting hazards all contribute to the need to be forward-thinking, not just in terms of how the climate will change but also in terms of how social conditions will evolve (Chang *et al.*, 2019b). Land-use planners can contribute significantly to conversations and decisions around hazard mitigation and can provide expertise that is not traditionally held by DRR professionals (Schwab, 2019). Some municipalities, such as Baltimore and New York City, are already beginning to recognize the connections between development decisions and DRR. Baltimore's integrated climate adaptation and local hazard mitigation plan was created with extensive involvement of city and community planners, who collaborated with emergency management professionals and sustainability specialists (City of Baltimore, 2018). New York City's post-Hurricane Sandy resilience planning recognizes that neighbourhood reconstruction and development needs to address local trends in development, specifically in the context of planned density (NYCDCP, 2020). Certain neighbourhoods are able to maintain planned density with climate-resilient retrofits, while other higher-risk areas may have to limit density through zoning and buy-outs to reduce exposure to future sea-level rise (NYCDCP, 2020).

6.2 Compelling Action to Improve Disaster Resilience

Governments can mandate the prioritization of prevention and mitigation activities at the individual, organizational, and municipal levels through legislation and regulation

Emergency management legislation at the provincial and territorial levels almost exclusively focuses on preparedness and response at the expense of the other stages (OAGO, 2017; Lindsay, 2018). In the Panel's view, this focus on preparedness and response interferes with the inclusion of many adaptation activities, which often have the greatest effect on prevention, mitigation, and recovery initiatives.

For the most part, the same local officials who hold power and responsibility for preparedness and response also hold the legal tools necessary for improvements to prevention, such as zoning and development regulation (Lindsay, 2018). However, municipalities often do not have adequate incentives or resources for reconciling these activities. In addition to financial support (Section 5.2.1) and access to appropriate information (Section 4.2.5), municipal governments can use relevant provincial legislation to mandate the inclusion of prevention and mitigation tools, largely through land-use planning (Lindsay, 2018). The following examples provide some models for how legislation could be implemented:

- In Quebec, the *Act Respecting Land Use Planning and Development* requires municipalities to develop plans that identify zones where land-use restrictions are necessary for public safety. These plans must be regularly updated and filed with regional and provincial authorities (Gov. of QC, 1979). The Act requires municipalities to then establish appropriate controls to mitigate hazards. Municipalities that fail to act upon these findings may also find their requests for post-disaster financial aid denied — for instance, if they knowingly allowed unrestricted development on hazardous land (Gov. of QC, 2021). These regulations are a powerful tool for undertaking mitigation activities (Lindsay, 2018).
- Once enacted, Nova Scotia's *Coastal Protection Act* will protect natural environments and limit construction and development in areas susceptible to sea-level rise and coastal flooding (Gov. of NS, 2019b). Proposed regulations include the creation of a Coastal Protection Zone, the development of new restrictions to coastal construction, and the enaction of setbacks for municipal building permits (Gov. of NS, 2021). To support the development of legislation, the government of Nova Scotia consulted with municipalities, First Nations interest groups, landowners, and other stakeholders, including professional associations, NGOs, tourism organizations, fisheries, and agriculture groups (Gov. of NS, 2019a).
- British Columbia's modernization of its emergency management legislation (to be introduced in 2022) is expected to reflect the priorities of global initiatives such as the Sendai Framework and the UN Declaration on the Rights of Indigenous Peoples, as well as lessons learned from COVID-19 and the 2017 and 2018 experiences with floods and wildfires (Gov. of BC, 2021). Importantly, all four phases of emergency management are to be addressed, and consultation with a wide range of stakeholders is ongoing (Gov. of BC, 2021).

Another solution is to explicitly create adaptation and resilience plans with an implementation focus (as opposed to focusing exclusively on planning) (Brown *et al.*, 2021). Complementary to this is the concept of mainstreaming, which involves the application of a climate change lens to all relevant policy decision-making (Lempert *et al.*, 2018) and has widespread traction in the adaptation community (Field *et al.*, 2014). When mainstreaming occurs, adaptation is proactive, as the changing climate is factored into routine decisions (Field *et al.*, 2014). Both Vancouver and Surrey have been mainstreaming adaptation into policies with the help of dedicated staff to drive interdepartmental coordination (Oulahen *et al.*, 2018). Further methods of compelling action to improve disaster resilience are mandatory and novel types of insurance (Section 5.2.2).

Requiring adherence to codes and standards that incorporate climate change adaptation is an important step for reducing the vulnerability of the built environment

Sections 3.3.1 and 4.2.5 discussed the importance of accounting for climate change in the development and updating of codes and standards for physical structures. Although there is progress on creating these standards, to realize their full potential, they must be invoked through legislation and regulation. For example, the National Plumbing Code of Canada requires that every new home have a backwater valve installed in both storm and sanitary sewers (NRC, 2015; Feltmate & Moudrak, 2021). However, since the National Plumbing Code is voluntary (as are the other national model codes, e.g., the National Building Code), provinces and territories ultimately decide which components of the code to integrate in their jurisdictions (Arsenault, 2019). Some provinces make backwater valves optional rather than mandatory, and the decision then comes down to the municipality, which can enforce an applicable bylaw (Feltmate & Moudrak, 2021). Requiring and enforcing codes at the municipal level is important for enhancing the resilience of individual homes and structures. However, strict enforcement through inspections, penalties, and the prosecution of law-breakers all take significant resources, leading governments to choose alternative tools for promoting compliance, such as recommendations, guidelines, and best practices (Quigley *et al.*, 2017). Although it may be less politically attractive, the Panel believes that exercising regulatory authority to achieve progress on both DRR and adaptation may become necessary to improve resilience.

Most design standards do not yet consider climate change impacts, though this is beginning to change (INFC, 2019d). Making codes that require increased consideration of climate change and disaster impacts compulsory is a powerful opportunity to achieve resilience in the building stock, though their adoption can also be encouraged through financial incentives (Section 5.2.1). In British

Columbia, the Ministry of Transportation and Infrastructure requires that climate change impacts be considered in the development of transportation infrastructure and provides the relevant guidance to do so (BCMOTI, 2019). In a municipal example, in 2014, the City of Vancouver mandated that minimum flood construction levels add one extra metre to account for projected sea-level rise by 2100 (City of Vancouver, 2014).

Municipalities also have a role to play in setting standards and bylaws to improve the resilience of structures. Provincial and territorial governments "assign responsibility to municipal officials to issue building permits, inspect the design and construction of new or altered buildings, and otherwise ensure compliance with the provincial building code and town by-laws" (Kovacs, 2010). Toronto has successfully used bylaws to reduce the impacts of climate change on physical infrastructure (Section 3.1). Bylaws can also be applied to setbacks or zoning, such as in the case of the Mill Creek Floodplain Bylaw in Kelowna, British Columbia. The bylaw concerns the position, design, and construction of buildings in the floodplain and stipulates a minimum setback distance and minimum elevations above groundwater level for buildings (City of Kelowna, 2010).

Holding institutions accountable for progress on advancing disaster resilience will promote sustained attention and effort

Disasters related to natural hazards are often described as "Acts of God" — situations that no one could have prevented. In these situations, nature is perceived to be at fault, and the most common reaction is to demand compensation from governments or insurers and then rebuild (Lavell & Maskrey, 2014). Increased global focus on climate change exacerbates this thinking; climate change is blamed for the impacts of hazards, distracting from pre-existing vulnerabilities stemming from decisions that put people in harm's way in the first place (Kelman *et al.*, 2017). This framing is starkly different from what are considered "human-caused disasters," such as transportation failures where there is a public outcry for accountability (Quigley *et al.*, 2017). In the case of disasters such as floods and fires, governments are often lauded for their preparedness and response activities without accounting for the lack of prevention and mitigation activities that could have prevented the disaster in the first place (Quigley *et al.*, 2017). This framing does not adequately hold decision-makers to account for actions that resulted in the exposure and vulnerability of populations and infrastructure (Kelman, 2020). For instance, following the damage to Fort McMurray in 2016, reconstruction was allowed in the floodway, even though it was not eligible for flood insurance (Bogdan *et al.*, 2020). When an ice jam in 2020 caused widespread flooding again, framing it as an Act of God absolved the government of responsibility to restrict development or enhance flood mitigation measures (Bogdan *et al.*, 2020).

Some are already starting to hold decision-makers accountable through lawsuits, making reference to the damage incurred through infrastructure neglect and deficient planning. Class-action lawsuits in Mississauga and Thunder Bay in Ontario have blamed municipal authorities for the flooding of residential properties (Clay, 2012; CBC News, 2013). This has also happened in Laval and Sainte-Marthe-sur-le-Lac in Quebec (Bogdan *et al.*, 2020; Giroux, 2020). The threat of future legal action may incentivize decision-makers to proactively reduce risk and promote resilience (Hill & Martinez-Diaz, 2020).

Another way to increase accountability is through public audits, which can provide external stakeholders with information on the activities of governments and decision-makers (Quigley *et al.*, 2017). In contrast to "human-caused" disasters, most disasters blamed on natural hazards do not have audits, and those that do tend to be narrowly focused on emergency response actions and are often quite positive. Encouraging independent audits to include investigations into past policy decisions that contributed to exposure and vulnerability would be useful for improving accountability (Quigley *et al.*, 2017).

Part of the problem for holding institutions accountable for decisions that contribute to increased exposure is a lack of tracking for prevention and mitigation activities, including adaptation. By assessing available documents and conducting interviews with adaptation practitioners in Ontario and Manitoba, Bednar *et al.* (2019) found that neither province had entered into stages that include monitoring and evaluation. This makes it difficult to assess how effective existing efforts are or if any progress is being made. In some situations, reporting only provides information on the activities that have taken place, not on the results (Sauchyn *et al.*, 2020). For example, Manitoba reports on climate change risks and adaptation activities but does not discuss the effectiveness of these actions for reducing or minimizing risks (AGM, 2017). At the federal level, PS does not publicly report on any activities related to prevention or mitigation; instead, it focuses exclusively on emergency response and preparedness (PS, 2020a). In the Panel's view, institutionalizing monitoring and tracking is an effective strategy for improving resilience through increased accountability. An independent group of experts advised the federal government on a set of adaptation and resilience indicators that could be used to assess progress in relation to the five key areas of adaptation work identified in the Pan-Canadian Framework (ECCC, 2018b). Many of these indicators apply to DRR — for example, Indicator #19, "percentage or number of communities with development and re-development 'build back better' control policies, bylaws and regulatory tools for climate-related hazards that are culturally appropriate and include Indigenous Knowledge Systems where appropriate," and Indicator #29, "number of people directly affected by a climate-related disaster" (ECCC, 2018b). It has also been suggested that one area of synergy for addressing the Sustainable Development Goals, Paris Agreement, and Sendai Framework is the development and implementation of targets and indicators that could measure progress on actions that contribute to all three agreements (UNCCS, 2017). Some provinces have also started their own tracking programs: Saskatchewan's climate change strategy involves 25 indicators in the areas of natural systems, physical infrastructure, economic sustainability, community preparedness, and human well-being (Gov. of SK, 2018).

6.3 Key Opportunities for Operationalizing Integration

Whole-of-society approaches, by definition, provide an avenue for the integration of all kinds of expertise necessary for advancing resilience, including land-use planners, engineers, insurers, NGOs, ILK holders, and residents. Within governments and organizations, individuals such as chief resilience officers break down barriers in communication among disparate groups and can drive the creation and implementation of integrated resilience plans, further motivating action on sustainability and equity. Finally, mandating the prioritization of prevention and mitigation activities at all orders of government provides an avenue for the integration of adaptation and planning expertise into DRR.

7

Towards a More Resilient Future

7.1 Choosing Resilience

7.2 Panel Reflections

In a changing climate, disasters pose an existential threat to Canadian communities. In recent years, catastrophic forest fires, heat waves, and floods have all contributed to a growing sense of urgency and recognition that much more needs to be done to confront mounting disaster risks. Reducing GHG emissions is essential to reducing and managing the threats posed by climate change. In addition to these reductions, much more can be done to keep people out of harm's way and to better prepare for the hazards that can least be avoided.

7.1 Choosing Resilience

Climate-related disasters are neither natural nor inevitable. The term natural disaster is increasingly recognized as a misnomer, and this report has avoided it where possible. Disasters result from the interactions between communities and naturally occurring hazards and are the consequences of human choices at individual and societal scales. Recognizing this is critical to creating accountability and motivating action. Resilience is a choice. Local communities can choose to build resilience through awareness-raising efforts, collaborative hazard mitigation endeavours, and engaging with local Indigenous capabilities and knowledge. Policy-makers can build resilience when disaster risks in a changing climate are factored into infrastructure, zoning, and funding choices. Researchers can integrate DRR and adaptation considerations into their work, engage with information users to identify important areas of focus, and package results in formats that are helpful for a range of audiences. Homeowners can work to understand local hazards and take steps to reduce their vulnerability and exposure through retrofits, preparedness measures, and landscaping. In the private sector, businesses can improve their competitiveness by assessing and managing the disaster risks they face in a changing climate by building in supply chain redundancies, for instance.

Recognizing that the future is not pre-determined and that opportunities for building resilience are widespread is essential to making progress. At the same time, the Panel recognizes that choices are often constrained. Communities and individuals often lack the necessary resources to pursue resilient strategies, and often the most vulnerable populations are least able to choose resilience owing to a wide range of constraints. Furthermore, choices are interdependent, and no one group can take on all the necessary steps to achieve resilience.

7.2 Panel Reflections

In response to its charge from Public Safety Canada, the Panel reviewed a wide range of evidence and examples of how governments and other stakeholders are integrating adaptation and DRR to enhance their resilience. One finding that emerges clearly from such a review is that there is no single right way (or tool or framework or approach) for bringing about this integration. Successful approaches are ones that are well adapted to their context. The Panel has highlighted many tools and resources for integration, some of which have been implemented in Canada and many of which have not. All-hazards risk assessments, accessible and tailored risk communication, nature-based solutions, community-wide engagement, well-designed insurance policies, and targeted public funding are among the opportunities available to enhance disaster resilience, sometimes with considerable co-benefits. A wide variety of lessons can be drawn from these examples, and their implications differ among governments, businesses, individuals, and other stakeholders. Taken as a whole, however, the overarching finding that emerges from all such evidence is simply that it is imperative to make the best possible use of all available resources when it comes to fostering resilience — regardless of the department or discipline in which they originate.

“Given that resources are scarce, focusing disaster resilience investments in areas that provide the greatest gains in well-being, rather than the highest financial return, is critical to addressing equity considerations.”

The integration of adaptation and DRR is only one means of improving resilience. Other opportunities also merit more research and attention. For example, efforts to bolster disaster resilience are often mutually reinforcing with those addressing other social needs, such as supporting vulnerable populations, reducing income inequality, and alleviating poverty. Part of enhancing disaster resilience is addressing the root causes of vulnerability and hazard exposure. There is more scope for collaboration between resilience-oriented policy and social and economic policy in many cases as a result. Similarly, further progress on reconciliation and Indigenous self-governance will advance resilience. A whole-of-society approach to building resilience includes a strong equity dimension by including groups likely to be the most affected by disasters in planning and decision-making. Given that resources are scarce, focusing disaster resilience investments in areas that provide the greatest gains in well-being, rather than the highest financial return, is critical to addressing equity considerations.

While the goal is always to avoid the occurrence of disasters, when they do unfold, they present important opportunities for learning, community building, and reinvestment. As society recovers from a disaster, choices are made that can either set the stage for the same set of events to unfold again or support rebuilding differently in ways that reduce exposure and vulnerability. Proactively developed recovery and resilience plans can prime communities to recover in a forward-looking and resilient manner, with incentives from FPT and local governments for their development and implementation. Disaster recovery therefore provides unique opportunities to build support and momentum across society for investments in resilience. In some cases, these opportunities extend well beyond the confines of a specific disaster. COVID-19 offers examples in some respects. COVID-19 fostered improved public risk literacy and drew attention to the global connectedness of society, illustrating the impacts and risks of widespread social and economic disruption and cascading hazards, as well as the potential for whole-of-society responses to manage a new and emerging hazard. Additionally, responses to the COVID-19 crisis contributed to advancing disaster resilience by applying a climate lens to economic stimulus funding.

Existing national frameworks for climate change and emergency management already acknowledge (and even prioritize) many of the concepts advanced in this report, including whole-of-society collaboration and governance, improved risk understanding, risk prevention and mitigation, and building forward better. The Pan-Canadian Framework identifies building climate-resilient infrastructure and reducing disaster risks among priority areas for adaptation. The development of a national adaptation strategy provides a significant opportunity to engage across Canada, advance integration, and ensure that strategies to advance adaptation and DRR are mutually reinforcing. Carrying this work forward effectively, however, will require paying greater attention to the barriers that frequently hinder progress and ensuring that future actions and investments are grounded in local context and needs.

Improving resilience in the face of a changing climate also requires greater awareness that society does not stand isolated or apart from the natural environment. The growing interest in NBSs reflects this understanding, but disasters are still typically framed in relatively narrow terms based primarily on human casualties and economic costs. While beyond the scope of this assessment, adverse impacts on natural systems can translate into adverse impacts on human communities, potentially causing or contributing to disasters. Activities such as draining wetlands and marshes for development, deforestation and ecosystem fragmentation, and the conversion of forests and grasslands to agriculture can reduce the resilience of existing ecosystems. Protecting ecosystems from climate-related hazards and fostering the resilience of conservation areas warrants more investigation in the Panel's view, as the services provided by these ecosystems contribute to managing and reducing climate change impacts. Here again, as with mitigating climate change in general and more proactively investing in resilience, the choices we collectively make today will determine the extent to which our communities remain vulnerable and exposed to climate-related hazards in the decades to come.

References

A.M. Best Company Inc. (2016). *Future Proofing: The Value of Natural Catastrophe Schemes in Europe*. Oldwick (NJ): A.M. Best Company Inc.

AAPPQ (Association des Architectes en pratique privée du Québec). (2018). News Release: Public Procurement Process – Protesting the Lowest Bidder Formula. Retrieved January 2021, from https://www.newswire.ca/news-releases/public-procurement-process---protesting-the-lowest-bidder-formula-690334441.html.

Abbott, G. & Chapman, M. (2018). *Addressing the New Normal: 21st Century Disaster Management in British Columbia*. Victoria (BC): Government of British Columbia.

AFN (Assembly of First Nations). (2017). *Assembly of First Nations Emergency Management Forum: Summary Report*. Ottawa (ON): AFN.

AGM (Auditor General of Manitoba). (2017). *Managing Climate Change*. Winnipeg (MB): AGM.

Agrawal, N. (2018). *Natural Disasters and Risk Management in Canada: An Introduction*. Toronto (ON): Springer.

AIDR (Australian Institute for Disaster Resilience). (2020). *Land Use Planning for Disaster Resilient Communities*. Melbourne, Australia: AIDR.

Ainslie, G. & Haslam, N. (1992). Hyperbolic Discounting. In G. Loewenstein & J. Elster (Eds.), *Choice Over Time*. New York (NY): Russell Sage Foundation.

Albright, E. (2019). Climate Change as a Transboundary Policymaking Natural Hazards Problem. In *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford, United Kingdom: Oxford University Press.

Albris, K., Lauta, K. C., & Raju, E. (2020). Disaster knowledge gaps: Exploring the interface between science and policy for disaster risk reduction in Europe. *International Journal of Disaster Risk Science, 11*(1), 1–12.

Amano, Y. (2013). *Flood Damage Statistics in Japan – What is Required for Mainstreaming DM?* Tokyo, Japan: Ministry of Land, Infrastructure, Transport and Tourism, Japan.

Amaratunga, D., Haigh, R., Dias, N., & Malalgoda, C. (2017). *Synthesis report of existing legal, policy and science approaches in relation to DRR and CCA*. Brussels, Belgium: European Union.

Andrachuk, M. & Smit, B. (2012). Community-based vulnerability assessment of Tuktoyaktuk, NWT, Canada to environmental and socio-economic changes. *Regional Environmental Change, 12*, 867–885.

Antoneshyn, A. (2020, May 4). $100M in Damage Caused in Fort McMurray Flood, Mayor Estimates, *CTV News*.

Arent, D. J., R.S.J. Tol, E. Faust, J.P. Hella, S. Kumar, K.M. Strzepek, . . . Yan, D. (2014). Key Economic Sectors and Services. In C. B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, . . . L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. New York (NY): Cambridge University Press.

Arsenault, C. (2019, April 11). Canada's Building Code is Getting a Climate Change Rewrite. Is Your Home Ready?, *CBC News*.

Ball, D. P. (2021, August 12). Extreme Heat Alerts Issued as Weather Agency Warns of Catch-22 from Smoke, High Temperatures, *CBC News*.

Ballard, M. & Thompson, S. (2013). Flooding hope and livelihoods: Lake St. Martin First Nation. *Canadian Journal of Nonprofit and Social Economy Research*, *4*(1), 43-65.

Barthel, F. & Neumayer, E. (2012). A trend analysis of normalized insured damage from natural disasters. *Climatic Change*, *113*, 215-237.

Bauer, F. & Smith, J. (Eds.). (2015). *The Climate Knowledge Brokers Manifesto*. Vienna, Austria: Renewable Energy and Energy Efficiency Partnership.

BCLA (British Columbia Lung Association). (2021). COVID-19 and Wildfire Smoke. Retrieved June 2021, from https://bc.lung.ca/patient-support/covid-19-and-wildfire-smoke.

BCMOTI, NCI, & PCIC (British Columbia Ministry of Transportation and Infrastructure, Nodelcorp Consulting Inc., and Pacific Climate Impacts Consortium). (2014a). *Developing Effective Dialogue between Practitioners of Climate Change Vulnerability-Risk Assessments: A Primer for Understanding Concepts, Principles and Language Use Across Disciplines*. Victoria (BC): BCMOTI.

BCMOTI, NCI, & PCIC (British Columbia Ministry of Transportation and Infrastructure, Nodelcorp Consulting Inc., and Pacific Climate Impacts Consortium). (2014b). *Considerations for Addressing Climate Change Adaptation for Transportation Infrastructure in Highway Management, Design, Operation and Maintenance in British Columbia: Best Practices Document*. Victoria (BC): BCMOTI.

BCMOTI (British Columbia Ministry of Transportation and Infrastructure). (2019). *Resilient Infrastructure Engineering Design - Adaptation to the Impacts of Climate Change and Weather Extremes: Technical Circular T-04/19*. Vancouver (BC): BCMOTI.

Beatley, T. (1998). The Vision of Sustainable Communities. In R. J. Burby (Ed.), *Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities*. Washington (DC): Joseph Henry Press.

Bednar, D., Henstra, D., & McBean, G. (2019). The governance of climate change adaptation: Are networks to blame for the implementation deficit? *Journal of Environmental Policy and Planning*, *21*(6), 702-717.

Beltrán, A., Maddison, D., & Elliott, R. (2019). The impact of flooding on property prices: A repeat-sales approach. *Journal of Environmental Economics and Management*, *95*, 62-86.

Berkowitz, M. (2014, July 7). What a Chief Resilience Officer Does, *The Rockefeller Foundation*.

Binder, S. B., Baker, C. K., & Barile, J. P. (2015). Rebuild or relocate? Resilience and postdisaster decision-making after Hurricane Sandy. *American Journal of Community Psychology, 56*, 180-196.

Binder, S. B. & Greer, A. (2016). The devil is in the details: Linking home buyout policy, practice, and experience after Hurricane Sandy. *Politics and Governance, 4*(4), 97-106.

Birkmann, J., von Teichman, K., Aldunce, P., Bach, C., Binh, N. T., Garschagen, M., . . . Thach, L. N. (2009). Addressing the Challenge: Recommendations and Quality Criteria for Linking Disaster Risk Reduction and Adaptation to Climate Change. In J. Birkmann, G. Tetzlaff & K.-O. Zentel (Eds.), *DKKV Publications Series 38*. Bonn, Germany: German Committee for Disaster Reduction.

Birkmann, J. & von Teichman, K. (2010). Integrating disaster risk reduction and climate change adaptation: Key challenges—scales, knowledge, and norms. *Sustainability Science, 5*(2), 171-184.

Birkmann, J., Cardona, O. D., Carreno, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., . . . Welle, T. (2013). Framing vulnerability, risk and societal responses: The MOVE framework. *Natural Hazards, 67*, 193-211.

Blaikie, P., Davis, I., Cannon, T., & Wisner, B. (1994). *At Risk: Natural Hazards, People's Vulnerability and Disasters* (1st ed.). New York (NY): Routledge.

Blaze Baum, K., Semeniuk, I., & McClearn, M. (2021, July 1). B.C.'s Heat Wave and Fires Were Driven by Climate Change, and They Won't Be the Last. What Must We Do Next?, *The Globe and Mail*.

BNQ (Bureau de Normalisation du Québec). (2013). *Reducing the Urban Heat Island Effect - Parking Lot Development - Design Guide*. Quebec (QC): BNQ.

Bogdan, E. A., Henstra, D., & Thistlethwaite, J. (2020, May 21). Fort McMurray's Flood Disaster was Foreseeable and Preventable, *The Conversation*.

Bolton, P., Despres, M., Pereira da Silva, L. A., Samama, F., & Svartzman, R. (2020). *The Green Swan: Central Banking and Financial Stability in the Age of Climate Change*. Basel, Switzerland: Bank for International Settlements.

Bonsal, B. R., Peters, D. L., Seglenieks, F., Rivera, A., & Berg, A. (2019). Chapter 6: Changes in Freshwater Availability Across Canada. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa (ON): Government of Canada.

Boudreault, M. (2021, March 31). Inondations au Québec: Qui Paie Pour Quoi et Comment, *The Conversation*.

Boulder County. (2016). Wildfire Partners Recognized as Model Community Wildfire Mitigation Program. Retrieved December 2020, from https://www.bouldercounty.org/news/wildfire-partners-recognized-as-model-community-wildfire-mitigation-program/.

Bowman, D. (2018). Wildfire science is at a loss for comprehensive data. *Nature, 560*(7).

Bowman, D. M. J. S., Kolden, C. A., Abatzoglou, J. T., Johnston, F. H., van der Werf, G. R., & Flannigan, M. D. (2020). Vegetation fires in the Anthropocene. *Nature Reviews Earth & Environment, 1*(10), 500-515.

Bräuninger, M., Butzengeiger-Geyer, S., Dlugolecki, A., Hochrainer, S., Köhler, M., Linnerooth-Bayer, J., . . . Schulze, S. (2011). *Application of Economic Instruments for Adaptation to Climate Change: Final Report*. Hamburg, Germany: Perspectives Climate Change.

Breummer, R. (2019, April 24). Is $200,000 a Fair Buyout Price for a House in a Quebec Flood Zone?, *Montreal Gazette*.

Brown, C., Jackson, E., Harford, D., & Bristow, D. (2021). Chapter 2: Cities and Towns. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report*. Ottawa (ON): Government of Canada.

Bryson, J. M., Crosby, B. C., & Middleton Stone, M. (2006). The design and implementation of cross-sector collaborations: Propositions from the literature. *Public Administration Review*(Special Issue), 44-55.

Bubeck, P., Otto, A., & Weichselgartner, J. (2017). Societal impacts of flood hazards. *Natural Hazard Science*.

Buchanan, J. M. (1975). The Samaritan's Dilemma. In E. S. Phelps (Ed.), *Altruism, Morality, and Economic Theory*. New York (NY): Russell Sage Foundation.

Burby, R. J. (1998). Natural Hazards and Land Use: An Introduction. In R. J. Burby (Ed.), *Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities*. Washington (DC): Joseph Henry Press.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature, 527*(7577), 235-239.

Bush, J. & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities, 95*(102483), 1-8.

Byerly, H., Meldrum, J. R., Brenkert-Smith, H., Champ, P., Gomez, J., Falk, L., & Barth, C. (2020). Developing behavioral and evidence-based programs for wildfire risk mitigation. *Fire, 3*(66).

Cannon, A. J., Jeong, D. I., Zhang, X., & Zwiers, F. W. (2020). *Climate-Resilient Buildings and Core Public Infrastructure: An Assessment of the Impact of Climate Change on Climatic Design in Canada*. Gatineau (QC): Environment and Climate Change Canada.

Cao, Z. (2008). Severe hail frequency over Ontario, Canada: Recent trend and variability. *Geophysical Research Letters, 35*(14).

Carlson, D., Eyring, V., van der Wel, N., & Langendijk, G. (2017). WCRP's Coupled Model Intercomparison Project: A Remarkable Contribution to Climate Science. Retrieved March 2021, from https://www.egu.eu/news/highlight-articles/586/wcrps-coupled-model-intercomparison-project-a-remarkable-contribution-to-climate-science/.

Carlson, H., Pietroniro, A., Gober, P., Leger, W., & Merrill, S. (2021). Chapter 4: Water Resources. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report*. Ottawa (ON): Government of Canada.

Carney, M. (2015). *Breaking the Tragedy of the Horizon – Climate Change and Financial Stability.* London, United Kingdom: Bank of England.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., . . . Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences, 100*(14), 8086.

CBC News. (2013, September 24). Thunder Bay $375M Flood Lawsuit Moves Ahead, *CBC News.*

CCA (Council of Canadian Academies). (2019a). *Greater Than the Sum of Its Parts: Toward Integrated Natural Resource Management in Canada*. Ottawa (ON): The Expert Panel on the State of Knowledge and Practice of Integrated Approaches to Natural Resource Management in Canada, CCA.

CCA (Council of Canadian Academies). (2019b). *Canada's Top Climate Change Risks*. Ottawa (ON): The Expert Panel on Climate Change Risks and Adaptation Potential, CCA.

CCC (Climate Change Committee). (2016). *UK Climate Change Risk Assessment 2017 Synthesis Report: Priorities for the Next Five Years*. London, United Kingdom: CCC.

CCC (Climate Change Committee). (2021). *Independent Assessment of UK Climate Risk: Advice to Governent for the UK's Third Climate Change Risk Assessment (CCRA3)*. London, United Kingdom: CCC.

CED (Climate Emergency Declaration). (2021). Climate Emergency Declarations in 2,025 Jurisdictions and Local Governments Cover 1 Billion Citizens. Retrieved November 2021, from https://climateemergencydeclaration.org/climate-emergency-declarations-cover-15-million-citizens/.

CFS (Canadian Forest Service). (2020). *Canadian Wildland Fire Evacuation Database*. Ottawa (ON): Natural Resources Canada.

Chang, S. E., McDaniels, T. L., Yumagulova, L., & Stevens, M. (2019a). Dynamics and Governance of Risk in Metro Vancouver. In T. A. Hutton & P. Gurstein (Eds.), *Planning on the Edge: Vancouver and the Challenges of Reconciliation, Social Justice, and Sustainable Development*. Vancouver (BC): UBC Press.

Chang, S. E., Yip, J. Z. K., & Tse, W. (2019b). Effects of urban development on future multi-hazard risk: The case of Vancouver, Canada. *Natural Hazards, 98*, 251–265.

Chapagain, J. & Steer, A. (2020). Why Disaster Preparedness Cannot Wait. Retrieved March 2021, from https://www.ifrc.org/article/why-disaster-preparedness-cannot-wait.

Chmutina, K., Jigyasu, R., & Bosher, L. (2017). Integrating Disaster Risk Reduction Including Climate Change Adaptation Into the Delivery and Management of the Built Environment. In I. Kelman, J. Mercer & J. C. Gaillard (Eds.), *The Routledge Handbook of Disaster Risk Reduction Including Climate Change Adaptation*. London, United Kingdom: Routledge.

Christianson, A. C., McGee, T. K., & L'Hirondelle, L. (2014). The influence of culture on wildfire mitigation at Peavine Métis Settlement, Alberta, Canada. *Society & Natural Resources, 27*(9), 931-947.

CICC (Canadian Institute for Climate Choices). (2021). *The Health Costs of Climate Change: How Canada Can Adapt, Prepare, and Save Lives*. Ottawa (ON): CICC.

CIP (Canadian Institute of Planners). (n.d.). *Model Standard of Practice for Climate Change Planning*. Ottawa (ON): CIP.

CIRC (Canadian Infrastructure Report Card). (2019). *Monitoring the State of Canada's Core Public Infrastructure*. CIRC.

Circé, M., Da Silva, L., Mercier, X., Boyer-Villemaire, U., Desjarlais, C., & Morneau, F. (2016). *Analyse Coûts-avantages des Options D'Adaptation en Zone Côtière à Percé.* Montréal (QC): Ouranos.

CIRNAC (Crown-Indigenous Relations and Northern Affairs Canada). (2019). Indigenous Community-Based Climate Monitoring Program: Funding Guidelines 2018-2019. Retrieved March 2019, from https://www.rcaanc-cirnac.gc.ca/eng/1512489182833/1594738437598.

City of Baltimore. (2018). *Disaster Preparedness and Planning Project (DP3): A combined all-hazard mitigation and climate adaptation plan*. Baltimore (MD): City of Baltimore.

City of Calgary. (n.d.). Calgary's River Flood Story. Retrieved June 2021, from https://maps.calgary.ca/riverflooding/.

City of Kelowna. (2010). *A Bylaw of the City of Kelowna to Designate Land as Flood Plain for Mill Creek and Regulate the Development of Land That is Subject to Flooding by Mill Creek*. Kelowna (BC): City of Kelowna.

City of Montréal. (2015). *Climate Change Adaptation Plan for the Agglomeration of Montreal 2015-2020*. Montréal (QC): City of Montréal.

City of Toronto. (2019). *Toronto's First Resilience Strategy*. Toronto (ON): City of Toronto.

City of Toronto. (2021a). Urban Forestry Grants & Incentives. Retrieved May 2021, from https://www.toronto.ca/business-economy/partnerships-sponsorships-donations/partner-2/parks-environment/urban-forestry-grants-and-incentives/.

City of Toronto. (2021b). Tree Planting. Retrieved May 2021, from https://www.toronto.ca/services-payments/water-environment/trees/tree-planting/.

City of Vancouver. (2014). *Flood Construction Levels*. Vancouver (BC): City of Vancouver.

City of Vancouver. (2019). *Rain City Strategy: A Green Rainwater Infrastructure and Rainwater Management Initiative*. Vancouver (BC): City of Vancouver.

City of Vancouver. (n.d.-a). Download the City's VanConnect app. Retrieved June 2021, from https://vancouver.ca/vanconnect.aspx.

City of Vancouver. (n.d.-b). Report Non-Emergency Flooding on City Streets and Sidewalks. Retrieved June 2021, from https://vancouver.ca/home-property-development/vanconnect-flooding.aspx.

City of Vancouver. (n.d.-c). Resilient Neighbourhoods Program. Retrieved July 2021, from https://vancouver.ca/people-programs/resilient-neighbourhoods-program.aspx.

Clark, D. (2020). When Disasters Collide. Retrieved March 2021, from https://climatechoices.ca/when-disasters-collide/.

Clark, T. D. (2017). *Natural Disasters, Vulnerability, and Resilience in Indigenous Communities: Literature Review and Conceptual Framework*. Cochrane (AB): Willow Springs Strategic Solutions.

Clarke, L., Nichols, L., Vallario, R., Hejaz, M., Horing, J., Janetos, A. C., . . . White, D. D. (2018). Sector Interactions, Multiple Stressors, and Complex Systems. In D. R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock & B. C. Stewart (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Washington (DC): U.S. Global Change Research Program.

Clay, C. (2012, June 14). Lisgar Flooding Leads to $200M Lawsuit, *Mississauga News*.

Cleary, K., Mathewson, S., Tran, A., Burkett, J., Causgrove, P., Feldman, J., . . . Ryan, K. (2018). *Uses of Catastrophe Model Output*. Washington (DC): American Academy of Actuaries.

Climate Action 100+. (2021a). The Three Asks. Retrieved October 2021, from https://www.climateaction100.org/approach/the-three-asks/.

Climate Action 100+. (2021b). Investor Signatories. Retrieved October 2021, from https://www.climateaction100.org/whos-involved/investors/.

Climate Atlas of Canada. (n.d.). Welcome to the Climate Atlas. Retrieved January 2021, from https://climateatlas.ca/.

Cloutier, M., Ribaux, R., & Cloutier, I. (2020, May 29). Social Capital in Montreal: A Vector for Community Resilience and the Ecological Transition, *Maison de l'innovation sociale*.

Conservation Ontario. (2013). *Dodging the 'Perfect Storm': Conservation Ontario's Business Case for Strategic Reinvestment in Ontario's Flood Management Programs, Services, and Structures*. Newmarket (ON): Conservation Ontario.

Cook, L. M., McGinnis, S., & Samaras, C. (2020). The effect of modeling choices on updating intensity-duration-frequency curves and stormwater infrastructure designs for climate change. *Climatic Change, 159*, 289–308.

Coppola, D. & Maloney, E. (2017). *Communicating Emergency Preparedness: Strategies for Creating a Disaster Resilient Public*. New York (NY): CRC Press Taylor and Francis Group.

Coronese, M., Lamperti, F., Keller, K., Chiaromonte, F., & Roventini, A. (2019). Evidence for sharp increase in the economic damages of extreme natural disasters. *Proceedings of the National Academy of Sciences, 116*(43), 21450.

CPA (Chartered Professional Accountants Canada). (2016). *How Chartered Professional Accountants Can Help Organizations Adapt to Climate Change*. Toronto (ON): CPA.

Craig, L., Craig, N., Calgaro, E., Dominey-Howes, D., & Johnson, K. (2019). Chapter 13 - People with Disabilities: Becoming Agents of Change in Disaster Risk Reduction. In F. I. Rivera (Ed.), *Emerging Voices in Natural Hazards Research*. Oxford, United Kingdom: Butterworth-Heinemann, Elsevier Inc.

CREW (Community Resilience to Extreme Weather). (n.d.-a). Extreme Weather Volunteers: Floor and Block Capitains. Retrieved April 2021, from http://www.crewtoronto.ca/our-projects/floor-and-block-captains/.

CREW (Community Resilience to Extreme Weather). (n.d.-b). About Us. Retrieved February 2021, from http://www.crewtoronto.ca/about-us/.

Cryderman, K. (2013, August 22). Alberta government offers to buy homes in flood-prone areas, *The Globe and Mail*.

CSA (Canadian Securities Administrators). (2019). *CSA Staff Notice 51-358: Reporting of Climate Change-related Risks*. Montréal (QC): CSA.

CSLA (Canadian Society of Landscape Architects). (2018). Adaptation Primers. Retrieved March 2021, from https://www.csla-aapc.ca/mission-areas/primers.

Curran, T. J., Perry, G. L. W., Wyse, S. V., & Alam, M. A. (2018). Managing fire and biodiversity in the wildland-urban interface: A role for green firebreaks. *Fire, 1*(3).

Cutter, S. L. (1996). Vulnerability to environmental hazards. *Progress in Human Geography, 20*(4), 529-539.

Darwish, L. (2018). *Dufferin County: Reducing the risk of wind damage by building stonger homes*. Toronto (ON): Institute for Catastrophic Loss Reduction.

Davis, P. K. (2002). *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation*. Santa Monica (CA): RAND.

Dawson, P. L., Richard. (2016). From science to survival: Using virtual exhibits to communicate the significance of polar heritage sites in the Canadian Arctic. *Open Archaeology,* 2, 209-231.

Delcan. (2012). *Cost of Adaptation - Sea Dikes & Alternative Strategies*. Victoria (BC): British Columbia Ministry of Forests, Lands and Natural Resource Operations.

Delica-Willison, Z., dela Cruz, L. B., & Molina, F. G. J. (2017). Communities Doing Disaster Risk Reduction Including Climate Change Adaptation. In I. Kelman, J. Mercer & J. Gaillard (Eds.), *The Routledge Handbook of Disaster Risk Reduction*. London, United Kingdom: Routledge.

Derksen, C., Burgess, D., Duguay, C., Howell, S., Mudryk, L., Smith, S., . . . Krchmeier-Young, M. (2019). Chapter 5: Changes in Snow, Ice, and Permafrost Across Canada. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa (ON): Government of Canada.

Dillon, R. L., Tinsley, C. H., & Cronin, M. (2011). Why near-miss events can decrease an individual's protective response to hurricanes. *Risk Analysis, 31*(3), 440-449.

Doberstein, B., Fitzgibbons, J., & Mitchell, C. (2019). Protect, accommodate, retreat or avoid (PARA): Canadian community options for flood disaster risk reduction and flood resilience. *Natural Hazards, 98*(1), 31-50.

ECCC (Environment and Climate Change Canada). (2018a). *Introduction to the MSC's Collaborative Monitoring Initiative*. Ottawa (ON): ECCC.

ECCC (Environment and Climate Change Canada). (2018b). *Measuring Progress on Adaptation and Climate Resilience: Recommendations to the Government of Canada*. Ottawa (ON): ECCC.

ECCC (Environment and Climate Change Canada). (2019a). *The MSC's Collaborative Monitoring Initiative & Risk Based Approach to Hydrometric Network Design*. Ottawa (ON): Meteorological Service of Canada.

ECCC (Environment and Climate Change Canada). (2019b). *Inuit Field Training Program*. Gatineau (QC): ECCC.

ECCC (Environment and Climate Change Canada). (2020a). *Climate Science 2050: Advancing Science and Knowledge on Climate Change*. Gatineau (QC): ECCC.

ECCC (Environment and Climate Change Canada). (2020b). *Pan-Canadian Framework on Clean Growth and Climate Change: Third Annual Synthesis Report on the Status of Implementation*. Gatineau (QC): ECCC.

ECCC (Environment and Climate Change Canada). (2021). *A Healthy Environment and a Healthy Economy: Canada's Strengthened Climate Plan to Create Jobs and Support People, Communities and the Planet*. Gatineau (QC): ECCC.

ECO (Environmental Commissioner of Ontario). (2018). *Climate Action in Ontario: What's Next? 2018 Greenhouse Gas Progress Report*. Toronto (ON): ECO.

EEA (European Environment Agency). (2017). *Climate Change Adaptation and Disaster Risk Reduction in Europe: Enhancing Coherence of the Knowledge Base, Policies and Practices*. Copenhagen, Denmark: EEA.

Eisenberg, R. (2018). How Permafrost Insurance Could Revolutionize Arctic Development. Retrieved July 2021, from https://www.arctictoday.com/permafrost-insurance-revolutionize-arctic-development/.

EMBC (Emergency Management BC). (2020). *Hazard, Risk and Vulnerability Analysis (HRVA) for Local Authorities and First Nations: Companion Guide for the HRVA Tool*. Saanichton (BC): EMBC.

EMV (Emergency Management Victoria). (2017). *Community Resilience Framework for Emergency Management*. Melbourne, Australia: EMV.

EMV (Emergency Management Victoria). (2018). *Creating Safer and More Resilient Communities: Emergency Management Victoria*. Victoria, Australia: EMV.

Engineers Canada. (2018). *Public Guidance: Principles of Climate Adaptation and Mitigation for Engineers*. Ottawa (ON): Engineers Canada.

Engineers Canada. (2019). *Request for Proposal: Public Infrastructure Engineering Vulnerability Committee (PIEVC) Program*. Ottawa (ON): Engineers Canada.

Engineers Canada. (n.d.). Infrastructure Resilience Professional (IRP) Designation. Retrieved February 2021, from https://engineerscanada.ca/services/infrastructure-resilience-professional.

ERCOT (Electric Reliability Council of Texas). (2017). ERCOT Responds to Hurricane Harvey. Retrieved June 2021, from http://www.ercot.com/help/harvey.

ESA (Electrical Safety Authority). (n.d.). Knob and Tube Wiring. Retrieved December 2020, from https://esasafe.com/home-renovation-buying-and-selling/knob-and-tube/.

Etkin, D. & Ho, E. (2007). Climate change: Perceptions and discourses of risk. *Journal of Risk Research, 10*(5), 623-641.

Etkin, D. (2010). *Canadians at Risk: Our exposure to natural hazards.* Toronto (ON): Institute for Catastrophic Loss Reduction.

Evans, M. & Carlson, J. (2012, November 3). Left in the Dark, *Modern Healthcare*.

Eves, C. (2002). The long-term impact of flooding on residential property values. *Property Management, 20*(4), 214-227.

Eyzaguirre, J. & Warren, F. J. (2014). Chapter 9: Adaptation: Linking Research and Practice. In F.J. Warren & D.S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation.* Ottawa (ON): Government of Canada.

Eyzaguirre, J., Nelitz, M., Stager, H., & Webb, T. (2018). *Scoping the Integration of Disaster Risk Reduction and Climate Change Adaptation in the Canadian Context*. Vancouver (BC): ESSA Technologies, Ltd.

Fahys, J. (2020, October 26). Long-Term Health Effects of Wildfire Smoke Feared, With COVID as Wild Card, *InsideClimate News*.

FBC (Fraser Basin Council). (2016). *Lower Mainland Flood Management Strategy: Phase 1 Summary Report.* Vancouver (BC): FBC.

FBC (Fraser Basin Council). (n.d.). Flood Management. Retrieved March 2021, from https://www.fraserbasin.bc.ca/water_flood.html.

FCM, UBC, & University of Waterloo (Federation of Canadian Municipalities, University of British Columbia, and University of Waterloo). (2019). *Local Adaptation in Canada: Survey Report*. Kelowna (BC): UBC.

FCM (Federation of Canadian Municipalities). (2021). A Northern Solution for Community Adaptation. Retrieved January 2021, from https://fcm.ca/en/resources/mcip/northern-solution-community-adaptation.

Feltmate, B. & Moudrak, M. (2016). *Climate Change and the Preparedness of Canadian Provinces and Yukon to Limit Potential Flood Damage.* Waterloo (ON): Intact Centre on Climate Adaptation, University of Waterloo.

Feltmate, B., Moudrak, N., Bakos, K., & Schofield, B. (2020). *Factoring Climate Risk into Financial Valuation*. Waterloo (ON): University of Waterloo.

Feltmate, B. & Moudrak, M. (2021). *Climate Change and the Preparedness of 16 Major Canadian Cities to Limit Flood Risk*. Waterloo (ON): Intact Centre on Climate Adaptation.

FEMA (Federal Emergency Management Agency). (2011). *A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action.* Washington (DC): FEMA.

FEMA (Federal Emergency Management Agency). (2020). *National Risk Index: Primer.* Washington (DC): FEMA.

FEMA (Federal Emergency Management Agency). (2021a). Risk Rating 2.0: Equity in Action. Retrieved July 2021, from https://www.fema.gov/flood-insurance/risk-rating.

FEMA (Federal Emergency Management Agency). (2021b). National Flood Insurance Program Community Rating System. Retrieved February 2021, from https://www.fema.gov/floodplain-management/community-rating-system.

Fiedler, T., Pitman, A. J., Mackenzie, K., Wood, N., Jakob, C., & Perkins-Kirkpatrick, S. E. (2021). Business risk and the emergence of climate analytics. *Nature Climate Change, 11*(2), 87–94.

Field, C. B., Barros, V. R., Mach, K. J., Mastrandrea, M. D., van Aalst, M., Adger, W. N., . . . Yohe, G. W. (2014). Technical Summary. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, . . . L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* New York (NY): Cambridge University Press.

FireSmart BC (FireSmart British Columbia). (n.d.). Indigenous Cultural Burning – Shackan. Retrieved August 2021, from https://firesmartbc.ca/resource/indigenous-cultural-burning-shackan/.

FireSmart Canada. (2018). *FireSmart Begins at Home Manual*. Edmonton (AB): FireSmart Canada.

FireSmart Canada. (2020). *Blazing the Trail: Celebrating Indigenous Fire Stewardship.* Sherwood Park (AB): FireSmart Canada.

First Street Foundation. (2020a). First Street Foundation Releases New Data Disclosing Flood Risk of Every U.S. Home. Retrieved January 2021, from https://firststreet.org/press/2020-first-street-foundation-flood-model-launch/.

First Street Foundation. (2020b). *The First National Flood Risk Assessment: Defining America's Growing Risk*. New York (NY): First Street Foundation.

Flato, G., Gillett, N., Arora, V., Cannon, A., & Anstey, J. (2019). Chapter 3: Modelling Future Climate Change. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report.* Ottawa (ON): Government of Canada.

Flavelle, C. (2020, August 26). U.S. Flood Strategy Shifts to 'Unavoidable' Relocation of Entire Neighborhoods, *The New York Times.*

Flint, C. G. & Stevenson, J. (2010). Building community disaster preparedness with volunteers: Community emergency response teams in Illinois. *Natural Hazards Review, 11*(3), 118-124.

Flood Re. (2018). *Our Vision: Securing a Future of Affordable Flood Insurance*. London, United Kingdom: Flood Re.

FNESS (First Nations' Emergency Services Society). (2021). First Nations Adapt Program (FNAP): Backgrounder - Infographics. Retrieved July 2021, from https://www.fness.bc.ca/core-programs/forest-fuel-management/first-nations-adapt-program.

Foster, J., Lowe, A., & Winkelman, S. (2011). *The Value of Green Infrastructure for Urban Climate Adaptation*. Washington (DC): The Center for Clean Air Policy.

Fothergill, A. (2000). Knowledge transfer between researchers and practitioners. *Natural Hazards Review, 1*(2), 91-98.

Frank, S., Gesick, E., & Victor, D. G. (2021). *Inviting Danger: How Federal Disaster, Insurance and Infrastructure Policies are Magnifying the Harm of Climate Change*. Washington (DC): Brookings Institution.

Frank, T. (2020, November 25). Riskiest Spot for Rising Seas Is 50 Miles from the Ocean, *Scientific American*.

FSCO (Financial Services Commission of Ontario). (2005). *Insurance Coverage Issues Affecting Older Homes*. Toronto (ON): FSCO.

Fuentes, R., Galeotti, M., Lanza, A., & Manzano, B. (2020). COVID-19 and climate change: A tale of two global problems. *Sustainability, 12*, 8560.

Funston, B. (2014). *Emergency Preparedness in Canada's North: An Examination of Community Capacity*. St. John's (NL): Harris Centre.

Gallagher, J. (2014). Learning about an infrequent event: Evidence from flood insurance take-up in the United States. *American Economic Journal: Applied Economics, 6*(3), 206-233.

Galloway, G. (2012, November 24). Flooded Out to Save Winnipeg, Lake St. Martin Residents Now Feel Forgotten, *The Globe and Mail*.

Galloway, G. (2018, August 6). 'It's Devastating to See': How a Rail Line Crisis is Threatening Churchill, Manitoba, *The Globe and Mail*.

Gaskin, C. J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). Factors associated with the climate change vulnerability and the adaptive capacity of people with disability: A systematic review. *Weather, Climate, and Society, 9*, 801-814.

GC (Government of Canada). (2007). *Emergency Management Act (S.C. 2007, c. 15)*. Ottawa (ON): GC.

GC (Government of Canada). (2016). *Pan-Canadian Framework on Clean Growth and Climate Change*. Ottawa (ON): Federal, Provincial, and Territorial Governments.

GC (Government of Canada). (2019a). Funding Opportunities to Support Adaptation Action. Retrieved December 2020, from https://www.canada.ca/en/environment-climate-change/services/climate-change/adapting/funding.html.

GC (Government of Canada). (2019b). *Emergency Management Strategy for Canada: Toward a Resilient 2030*. Ottawa (ON): Public Safety Canada.

GC (Government of Canada). (2019c). *Final Report of the Expert Panel on Sustainable Finance: Mobilizing Finance for Sustainable Growth*. Gatineau (QC): GC.

GC (Government of Canada). (2019d). *Investing in the Middle Class: Budget 2019*. Ottawa (ON): GC.

GC (Government of Canada). (2020). About the Canadian Centre for Climate Services. Retrieved February 2020, from https://www.canada.ca/en/environment-climate-change/services/climate-change/canadian-centre-climate-services/about.html.

GC (Government of Canada). (2021a). Why Does Canada Want to Implement the United Nations Declaration on the Rights of Indigenous Peoples? Retrieved March 2021, from https://www.justice.gc.ca/eng/declaration/why-pourquoi.html.

GC (Government of Canada). (2021b). *Adapting to the Impacts of Climate Change in Canada: An Update on the National Adaptation Strategy*. Gatineau (QC): GC.

GC (Government of Canada). (2021c). *A Recovery Plan for Jobs, Growth, and Resilience: Budget 2021*. Ottawa (ON): GC.

GC (Government of Canada). (n.d.). *Integrating Capability-Based Planning into the Canadian Emergency Management System*. Ottawa (ON): GC.

GCA (Global Commission on Adaptation). (2019). *Adapt Now: A Global Call for Leadership on Climate Resilience*. Rotterdam, The Netherlands: Global Center on Adaptation & World Resources Institute.

Giorgi, F., Jones, C., & Asrar, G. R. (2009). Addressing climate information needs at the regional level: The CORDEX framework. *WMO Bulletin, 58*(3), 175–183.

Giroux, S. (2020, January 8). Laval Residents Affected by Flooding Request Class Action Lawsuit, *CTV News*.

Glick, P., Powell, E., Schlesinger S., Ritter, J., Stein, B.A., Fuller, A. (2020). *The Protective Value of Nature: A Review of the Effectiveness of Natural Infrastructure for Hazard Risk Reduction*. Washington (DC): National Wildlife Federation.

Gneezy, A., Imas, A., & Jaroszewicz, A. (2020). The impact of agency on time and risk preferences. *Nature Communications, 11*, 1-9.

Golnaraghi, M., Surminski, S., & Schanz, K.-U. (2016). *An Integrated Approach to Managing Extreme Events and Climate Risks: Executive Summary and Policy Brief.* Zurich, Switzerland: The Geneva Association.

Golnaraghi, M., Muir-Wood, R., Guin, J., Whitaker, D., Slingo, J., Asrar, G., . . . Beck, M. (2018). *Managing Physical Climate Risk: Leveraging Innovations in Catastrophe Risk Modelling*. Zurich, Switzerland: The Geneva Association.

Goodison, B. E., Louie, P. Y. T., & Yang, D. (1998). *WMO Solid Precipitation Measurement Intercomparison: Final Report*. Geneva, Switzerland: World Meteorological Association.

Gov. of BC (Government of British Columbia). (2019). *Resilient Infrastructure Engineering Design – Adaptation to the Impacts of Climate Change and Weather Extremes*. Vancouver (BC): BC Ministry of Transportation and Infrastructure.

Gov. of BC (Government of British Columbia). (2021). Modernized Emergency Management Legislation. Retrieved March 2021, from https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/emergency-management-bc/legislation-and-regulations/modernizing-epa.

Gov. of BC (Government of British Columbia). (n.d.-a). Behavioural Insights. Retrieved March 2021, from https://www2.gov.bc.ca/gov/content/governments/services-for-government/service-experience-digital-delivery/behavioural-insights.

Gov. of BC (Government of British Columbia). (n.d.-b). Dike Management. Retrieved August 2021, from https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management.

Gov. of NB (Government of New Brunswick). (2002). *New Brunswick Wetlands Conservation Policy*. Fredericton (NB): Gov. of NB.

Gov. of NS (Government of Nova Scotia). (2019a). *Public and Stakeholder Consultations on Coastal Protection Legislation in Nova Scotia*. Halifax (NS): Gov. of NS.

Gov. of NS (Government of Nova Scotia). (2019b). *Coastal Protection Act*. Halifax (NS): General Assembly of Nova Scotia.

Gov. of NS (Government of Nova Scotia). (2021). *Proposed Coastal Protection Act Regulations*. Halifax (NS): Gov. of NS.

Gov. of ON (Government of Ontario). (2020a). Ontario Launching COVID-19 Resilience Infrastructure Stream. Retrieved December 2020, from https://news.ontario.ca/en/release/58972/ontario-launching-covid-19-resilience-infrastructure-stream.

Gov. of ON (Government of Ontario). (2020b). *Behavioural Insights in Ontario: Update Report 2020*. Toronto (ON): Gov. of ON.

Gov. of QC (Government of Quebec). (1979). Act Respecting Land Use Planning and Development (R.S.Q., c. A-19.1). Retrieved March 2020, from https://www.ecolex.org/details/legislation/act-respecting-land-use-planning-and-development-rsq-c-a-191-lex-faoc052906/.

Gov. of QC (Government of Quebec). (2021). *Civil Protection Act, CQLR c S-2.3*. Quebec (QC): CanLII.

Gov. of SK (Government of Saskatchewan). (2018). *Saskatchewan's Climate Resilience Measurement Framework*. Regina (SK): Gov. of SK.

Greenan, B. J. W., James, T. S., Loder, J. W., Pepin, P., Azetsu-Scott, K., Ianson, D., . . . Perrie, W. (2019). Chapter 7: Changes in Oceans Surrounding Canada. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa (ON): Government of Canada.

GRID-Arendal. (2020). Northern Perspectives. Retrieved July 2021, from https://storymaps.arcgis.com/stories/74bf8d1540c542b7a444a5a2ba1559e2.

Grothmann, T. & Reusswig, F. (2006). People at risk of flooding: Why some residents take precautionary action while others do not. *Natural Hazards, 38*(1), 101-120.

Groupe Agéco. (2019). *Vers de Grandes Villes Résilientes : Le Coût de L'Adaptation aux Changements Climatiques*. Québec (QC): Groupe Agéco.

GVS (Gathering Voices Society). (n.d.). Revitalizing Traditional Fire Management in Tsilhqot'in Territory. Retrieved February 2021, from https://www.gatheringvoices.com/tsilhqotin1.

Hansen, K. (2018, November 13). When Churchill Needed Ottawa, the Town was Ignored. Now, Ottawa Needs Churchill, *Macleans*.

Hayhoe, K., Wuebbles, D. J., Easterling, D. R., Fahey, D. W., Doherty, S., Kossin, J., . . . Wehner, M. (2018). Our Changing Climate. In D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock & B. C. Stewart (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* Washington (DC): U.S. Global Change Research Program.

Hazlewood, J. (2020, July 8). Heatwaves 'Devastating' for People Living on Waterloo Region's Streets, *CBC News*.

HC (Health Canada). (2011). *Adapting to Extreme Heat Events: Guidelines for Assessing Health Vulnerability*. Ottawa (ON): HC.

Healy, A. & Malhotra, N. (2009). Myopic voters and natural disaster policy. *American Political Science Review, 103*, 387-406.

Henstra, D. (2013). Introduction: Multilevel Governance and Canadian Emergency Management Policy. In D. Henstra (Ed.), *Multilevel Governance and Emergency Management in Canadian Municipalities*. Kingston (ON): McGill-Queen's University Press.

Henstra, D. & Thistlethwaite, J. (2017). *Climate Change, Floods, and Municipal Risk Sharing in Canada*. Toronto (ON): Institute on Municipal Finance & Governance and Munk School of Global Affairs.

Henstra, D., Thistlethwaite, J., & Dordi, T. (2020). Evaluating the suitability of policy instruments for urban flood risk reduction. *Local Environment, 25*(2), 101–113.

Henstra, D., Thistlethwaite, J. (2017). *Overcoming Barriers to Meeting the Sendai Framework for Disaster Risk Reduction*. Waterloo (ON): Centre for International Governance Innovation.

Hewitt, K. (1983). *Interpretations of Calamity from the Viewpoint of Human Ecology*. Winchester (MA): Allen and Unwin, Inc.

Hewitt, R. J., Hernandez-Jimenez, V., Zazo-Moratalla, A., Ocon-Martin, B., Roman-Bermejo, L. P., & Encinas-Escribano, M. A. (Eds.). (2017). *Participatory Modelling for Resilient Futures: Action for Managing Our Environment from the Bottom-Up* (Vol. 30). Amsterdam, The Netherlands: Elsevier.

Hill, A. C. & Martinez-Diaz, L. (2020). *Building a Resilient Tomorrow: How to Prepare for the Coming Climate Disruption*. New York (NY): Oxford University Press.

Ho, V. (2020, September 9). Hundreds of Thousands Brace for Power Shutoffs as California Fires Burn 2M Acres, *The Guardian*.

HoC (House of Commons). (2018). *From the Ashes: Reimagining Fire Safety and Emergency Management in Indigenous Communities: Report of the Standing Committee on Indigenous and Northern Affairs*. Ottawa (ON): Government of Canada.

HoC (House of Commons). (2019). 42nd Parliament, 1st Session - Vote No. 1366: Government Business No. 29 (National Climate Emergency). Retrieved March 2021, from https://www.ourcommons.ca/Members/en/votes/42/1/1366.

Holzheu, T. & Turner, G. (2018). The natural catastrophe protection gap: Measurement, root causes and ways of addressing underinsurance for extreme events. *The Geneva Papers on Risk and Insurance - Issues and Practice, 43*(1), 37–71.

Howes, M., Grant-Smith, D., Reis, K., Bosomworth, K., Tangney, P., Heazle, M., . . . Burton, P. (2013). *Rethinking Disaster Risk Management and Climate Change Adaptation*. Gold Coast, Australia: National Climate Change Adaptation Research Facility.

Howitt, R., Havnen, O., & Veland, S. (2012). Natural and unnatural disasters: Responding with respect for Indigenous rights and knowledges. *Geographical Research, 50*(1), 47–59.

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., . . . Houser, T. (2017). Estimating economic damage from climate change in the United States. *Science, 356*.

HUD (US Department of Housing and Urban Development). (2019). *Allocations, Common Application, Waivers, and Alternative Requirements for Community Development Block Grant Mitigation Grantees*. Washington (DC): HUD.

HUD (US Department of Housing and Urban Development). (2021). CDBG-MIT Overview. Retrieved July 2021, from https://www.hudexchange.info/programs/cdbg-mit/overview/.

Hurlbert, M., Krishnaswamy, J., Davin, E., Johnson, F. X., Mena, C. F., Morton, J., . . . Zommers, Z. (2019). Chapter 7: Risk Management and Decision Making in Relation to Sustainable Development. In P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, . . . J. Malley (Eds.), *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

IBC (Insurance Bureau of Canada). (2019). *Options for Managing the Flood Costs of Canada's Highest Risk Residential Properties*. Ottawa (ON): IBC.

IBC (Insurance Bureau of Canada). (2020a). Buying Home Insurance. Retrieved December 2020, from http://www.ibc.ca/ns/home/buying-home-insurance.

IBC (Insurance Bureau of Canada). (2020b). Backwater Valve. Retrieved December 2020, from http://www.ibc.ca/pe/home/risk-management/mitigation-techniques/backwater-valve.

IBC (Insurance Bureau of Canada). (2021). Severe Weather Caused $2.4 Billion in Insured Damage in 2020. Retrieved February 2021, from http://www.ibc.ca/on/resources/media-centre/media-releases/severe-weather-caused-$2-4-billion-in-insured-damage-in-2020.

IBC & FCM (Insurance Bureau of Canada and Federation of Canadian Municipalities). (2020). *Investing in Canada's Future: The Cost of Climate Adaptation at the Local Level*. Toronto (ON): IBC & FCM.

ICF. (2018). *Best Practices and Resources on Climate Resilient Natural Infrastructure*. Ottawa (ON): Canadian Council of Ministers of the Environment.

ICLR (Institute for Catastrophic Loss Reduction). (2021). *Focus on Types of Flooding*. Toronto (ON): ICLR.

ICLR & FIDS (Institute for Catastrophic Loss Reduction and Facility for Intelligent Decision Support). (2021). About the IDF_CC Tool. Retrieved February 2021, from https://www.idf-cc-uwo.ca/About.

IISD (International Institute for Sustainable Development). (2021). *Advancing the Climate Resilience of Canadian Infrastructure: A Review of Literature to Inform the Way Forward.* Winnipeg (MB): IISD.

IMF (International Monetary Fund). (2020). *Global Financial Stability Report.* Washington (DC): IMF.

IMF (International Monetary Fund). (2021). Remarks by IMF Managing Director at the Climate Adaptation Summit. Retrieved January 2021, from https://www.imf.org/en/News/Articles/2021/01/25/sp012521-md-remarks-at-the-climate-adaptation-summit.

INAC (Indigenous and Northern Affairs Canada). (2017). *Evaluation of the Emergency Management Assistance Program*. Gatineau (QC): INAC.

INFC (Infrastructure Canada). (2019a). Disaster Mitigation and Adaptation Fund. Retrieved January 2020, from https://www.infrastructure.gc.ca/dmaf-faac/index-eng.html.

INFC (Infrastructure Canada). (2019b). Climate Lens: General Guidance. Retrieved March 2021, from https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html.

INFC (Infrastructure Canada). (2019c). Canada Helps Protect Inuvik Mike Zubko Airport from Impacts of Climate Change. Retrieved July 2021, from https://www.newswire.ca/news-releases/canada-helps-protect-inuvik-mike-zubko-airport-from-impacts-of-climate-change-856761893.html.

INFC (Infrastructure Canada). (2019d). Climate-Resilient Buildings and Core Public Infrastructure Initiative. Retrieved February 2020, from https://www.infrastructure.gc.ca/plan/crbcpi-irccipb-eng.html.

INFC (Infrastructure Canada). (2020a). Backgrounder: Infrastructure Program Expands to Support COVID-19 Community Resilience. Retrieved March 2021, from https://www.canada.ca/en/office-infrastructure/news/2020/08/backgrounder-infrastructure-program-expands-to-support-covid-19-community-resilience.html.

INFC (Infrastructure Canada). (2020b). Infrastructure Canada's Funding Programs. Retrieved January 2020, from https://www.infrastructure.gc.ca/prog/programs-infc-summary-eng.html#dmaf.

IOG (Institute on Governance). (2018). *Evaluation of the PCO Central Innovation Hub.* Ottawa (ON): IOG.

IPCC (Intergovernmental Panel on Climate Change). (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge, United Kingdom and New York (NY): Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC.

IPCC (Intergovernmental Panel on Climate Change). (2018). Annex I: Glossary. In J. B. R. Matthews (Ed.), *Special Report: Global Warming of 1.5°C*. In Press.

IPCC (Intergovernmental Panel on Climate Change). (2021). IPCC, 2021: Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, . . . B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. In Press: Cambridge University Press.

IRF (International River Foundation). (2021a). Thiess International River Prize. Retrieved July 2021, from https://riverfoundation.org.au/our-programs/riverprize/international-riverprize-2021/.

IRF (International River Foundation). (2021b). Previous Thiess International River Prize Award Winners. Retrieved July 2021, from https://riverfoundation.org.au/our-programs/riverprize/international-riverprize/previous-international-riverprize-winners/.

Isai, V. (2021, July 10). Heat Wave Spread Fire That Erased' Canadian Town, *The New York Times*.

ISC (Indigenous Services Canada). (2019a). Graph of Costs Reimbursed. Retrieved January 2020, from https://www.sac-isc.gc.ca/eng/1560363002018/1560363016109.

ISC (Indigenous Services Canada). (2019b). Emergency Management Assistance Program. Retrieved January 2020, from https://www.sac-isc.gc.ca/eng/1534954090122/1535120506707.

ISC (Indigenous Services Canada). (2020). *Contributions for Emergency Management Assistance for Activities on Reserve: Terms and Conditions*. Ottawa (ON): ISC.

ISO (International Organization for Standardization). (2020). *Guidelines for Addressing Climate Change in Standards*. Geneva, Switzerland: ISO.

ITK (Inuit Tapiriit Kanatami). (2016). *Inuit Priorities for Canada's Climate Strategy: A Canadian Inuit Vision for Our Common Future in Our Homelands*. Ottawa (ON): ITK.

ITK (Inuit Tapiriit Kanatami). (2019). *National Inuit Climate Change Strategy*. Ottawa (ON): ITK.

Jackson, H. (2019, June 17). National Climate Emergency Declared by House of Commons, *Global News*.

JHCRC (Johns Hopkins Coronavirus Resource Center). (2021). COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU). Retrieved February 2021, from https://coronavirus.jhu.edu/map.html.

Jia, G., Shevliakova, E., Artaxo, P., De Noblet-Ducoudré, N., Houghton, R., House, J., . . . Verchot, L. (2019). Chapter 2: Land–climate interactions. In P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, . . . J. Malley (Eds.), *Climate Change and Land: An IPCC Special Report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Johnston, L. M. & Flannigan, M. D. (2018). Mapping Canadian wildland fire interface areas. *International Journal of Wildland Fire*, 27, 1-14.

Juillet, L., Koji, J. (2013). Policy Change and Constitutional Order: Municipalities, Intergovernmental Relations, and the Recent Evolution of Canadian Emergency Management Policy. In D. Henstra (Ed.), *Multilevel Governance and Emergency Management in Canadian Municipalities*. Montreal (QC) and Kingston (ON): McGill-Queen's University Press.

JUS (Department of Justice). (2018). *Principles Respecting the Government of Canada's Relationship with Indigenous Peoples*. Ottawa (ON): Government of Canada.

Kahn, M. E. (2015). Climate change adaptation will offer a sharp test of the claims of behavioral economics. *The Economists' Voice, 12*(1), 25-30.

Kahneman, D. & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*(2), 263-291.

Kahneman, D. (2011). *Thinking, Fast and Slow.* New York (NY): Farrar, Straus and Giroux.

Keller, J. & McClearn, M. (2020, May 21). Why Fort McMurray's Flood Defences Weren't Ready When the Town Needed Them Most, *The Globe and Mail*.

Kelman, I., Mercer, J., & Gaillard, J. C. (2017). Why Act on Disaster Risk Reduction Including Climate Change Adaptation? In I. Kelman, J. Mercer & J. C. Gaillard (Eds.), *The Routledge Handbook of Disaster Risk Reduction Including Climate Change Adaptation*. London, United Kingdom: Routledge.

Kelman, I. (2018). Lost for words amongst disaster risk science vocabulary? *International Journal of Disaster Risk Science, 9*, 281-291.

Kelman, I. (2020). *Disaster by Choice*. New York (NY): Oxford University Press.

Kenney, C. M. & Phibbs, S. (2015). A Māori love story: Community-led disaster management in response to the Ōtautahi (Christchurch) earthquakes as a framework for action. *International Journal of Disaster Risk Reduction, 14*, 46-55.

King-Scobie, C. (2019). *Urban Flood Management and Disaster in Canada: Incidence, Recovery Strategy, and Environmental Resilience*. Vancouver (BC): University of British Columbia.

King, D., Gurtner, Y., Firdaus, A., Harwood, S., & Cottrell, A. (2016). Land use planning for disaster risk reduction and climate change adaptation: Operationalizing policy and legislation at local levels. *International Journal of Disaster Resilience in the Built Environment, Development and Sustainability,* 7(2), 158-172.

Kirchmeier-Young, M. C., Wan, H., & Zhang, X. (2021). Anthropogenic contribution to the rainfall associated with the 2019 Ottawa river flood. *Bulletin of the American Meteorological Society, 102*, S33-S38.

Klima, K. & Morgan, M. G. (2015). Ice storm frequencies in a warmer climate. *Climatic Change, 133*(2), 209-222.

Klinenberg, E. (2015, October 27). Is New York Ready for Another Sandy?, *The New Yorker.*

Koliba, C. J., Mills, R. M., & Zia, A. (2011). Accountability in governance networks: An assessment of public, private, and nonprofit emergency management practices following Hurricane Katrina. *Public Administration Review, 71*(2), 210-220.

Kousky, C. & Kunreuther, H. (2014). Addressing affordability in the National Flood Insurance Program. *Journal of Extreme Events, 01*(01), 1450001.

Kousky, C., Michel-Kerjan, E. O., & Raschky, P. A. (2018). Does federal disaster assistance crowd out flood insurance? *Journal of Environmental Economics and Management, 87*, 150-164.

Kousky, C. (2019). The role of natural disaster insurance in recovery and risk reduction. *Annual Review of Resource Economics, 11*(1), 399-418.

Kousky, C., Palim, M., & Pan, Y. (2020). Flood damage and mortgage credit risk: A case study of Hurricane Harvey. *Journal of Housing Research, 29*(sup1), S86-S120.

Kovacs, K., Beal, G., Golnaraghi, M., Koval, P., McBean, G., & Li, B. (2021). Chapter 8: Climate Disclosure, Litigation and Finance. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report*. Ottawa (ON): Government of Canada.

Kovacs, P. (2010). *Reducing the Risk of Earthquake Damage in Canada: Lessons from Haiti and Chile*. Toronto (ON): Institute for Catastrophic Loss Reduction.

Kovacs, P., Guilbault, S., & Sandink, D. (2014). *Cities Adapt to Extreme Rainfall: Celebrating Local Leadership*. Toronto (ON): Institute for Catastrophic Loss Reduction.

Kovacs, P. (2018). *Development Permits: An Emerging Policy Instrument for Local Governments to Manage Interface Fire Risk in a Changing Climate*. Toronto (ON): Institute for Catastrophic Loss Reduction.

Krawchuk, M. A., Cumming, S. G., Flannigan, M. D., & Wein, R. W. (2006). Biotic and abiotic regulation of lighting fire initiation in the mixedwood boreal forest. *Ecology, 87*(2), 458-468.

Kuhlicke, C., Seebauer, S., Hudson, P., Begg, C., Bubeck, P., Dittmer, C., . . . Bamberg, S. (2020). The behavioral turn in flood risk management, its assumptions and potential implications. *WIREs Water,* 7(3), e1418.

Kunda, Z. (1990). The case for motivated reasoning. *Psychological Bulletin, 108*(3), 480-498.

Kunreuther, H. (2015). The role of insurance in reducing losses from extreme events: The need for public–private partnerships. *The Geneva Papers on Risk and Insurance - Issues and Practice, 40*(4), 741–762.

KWL (Kerr Wood Leidal Associates Ltd.). (2020). *Draft North Shore Sea Level Rise Risk Assessment & Adaptive Management Strategy*. Vancouver (BC): KWL.

Lall, U., Johnson, T., Colohan, P., Aghakouchak, A., Brown, C., McCabe, G., . . . Sankarasubramanian, A. (2018). Water. In D. R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock & B. C. Stewart (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Washington (DC): U.S. Global Change Research Program.

Lamond, J. & Penning-Rowsell, E. (2014). The robustness of flood insurance regimes given changing risk resulting from climate change. *Climate Risk Management,* 2, 1–10.

Lavell, A. & Maskrey, A. (2014). The future of disaster risk management. *Environmental Hazards, 13*(4), 267-280.

Lemos, M. C. & Rood, R. B. (2010). Climate projections and their impact on policy and practice. *WIREs Climate Change, 1*(5), 670-682.

Lempert, R., Arnold, J., Pulwarty, R., Gordon, K., Greig, K., Hoffman, C. H., . . . Werrell, C. (2018). Reducing Risks Through Adaptation Actions. In D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock & B. C. Stewart (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* Washington (DC): U.S. Global Change Research Program.

Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., & Schellnhuber, H. J. (2019). Climate tipping points: Too risky to bet against. *Nature, 575*(7784), 592-595.

Li, C., Banholzer, S., Callihoo, C., & Felio, G. (2019). *Seeing through a New Climate Lens: Canada's Policy Approach to Climate-Resilient Infrastructure.* Paper presented at International Conference on Sustainable Infrastructure.

Li, L. & Chakraborty, P. (2020). Slower decay of landfalling hurricanes in a warming world. *Nature, 587*(7833), 230-234.

Lieske, D. J., Wade, T., & Roness, L. A. (2014). Climate change awareness and strategies for communicating the risk of coastal flooding: A Canadian Maritime case example. *Estuarine, Coastal and Shelf Science, 140*, 83-94.

Lindell, M. K., Arlikatti, S., & Prater, C. S. (2009). Why people do what they do to protect against earthquake risk: Perceptions of hazard adjustment attributes. *Risk Analysis, 29*(8), 1072-1088.

Lindell, M. K. & Perry, R. W. (2012). The protective action decision model: Theoretical modifications and additional evidence. *Risk Analysis, 32*(4), 616-632.

Lindsay, J. (2018). Natural Hazards Governance in Canada. In *Oxford Research Encyclopedia of Natural Hazard Science.* Oxford, United Kingdom: Oxford University Press.

Linnemayr, S., O'Hanlon, C., Uscher-Pines, L., Van Abel, K., & Nelson, C. (2016). Using insights from behavioral economics to strengthen disaster preparedness and response. *Disaster Medicine and Public Health Preparedness, 10*(5), 768-774.

Liu, K. & Bass, B. (2005). *Performance of Green Roof Systems.* Toronto (ON): National Research Council Canada.

Lloyds. (2014). *Catastrophe Modelling and Climate Change.* London, United Kingdom: Lloyds.

Lo, A. (2013). The role of social norms in climate adaptation: Mediating risk perception and flood insurance purchase. *Global Environmental Change, 23*, 1249–1257.

Luna, E. M. (2017). Education and Training for Disaster Risk Reduction Including Climate Change Adaptation. In I. Kelman, J. Mercer & J. C. Gaillard (Eds.), *The Routledge Handbook of Disaster Risk Reduction Including Climate Change Adaptation.* London, United Kingdom: Routledge.

Lund University. (n.d.). Disaster Risk Management and Climate Change Adaptation - Master's Programme. Retrieved July 2021, from https://www.lunduniversity.lu.se/lubas/i-uoh-lu-TAKAK.

Lyle, T. S. & Hund, S. V. (2017). *Way Forward for Risk Assessment Tools in Canada*. Ottawa (ON): Geological Survey of Canada.

MacKinnon, J., Heldsinger, N., & Peddle, S. (2018). *A Community Guide to Effective Flood Risk Communication: Promoting Personal Preparedness.* Waterloo (ON): Partners for Action.

MacLean, C. (2017, July 8). Churchill, Man., Weighs Risk of Climate Change on Future of Port, Railway, *CBC*.

Mailhot, A., Duchesne, S., Larrivée, C., Pelletier, G., Bolduc, S., Rondeau, F., . . . Talbot, G. (2008). *Conception et Planification des Interventions de Renouvellement des Infrastructures de Drainage Urbain dans un Contexte D'Adaptation aux Changements Climatiques.* Ottawa (ON): Natural Resources Canada and Ouranos.

Malik, A. (2020, February 14). How the P&C Industry Can Help Move the Needle on Building a Climate-Resilient Society, *Canadian Underwriter.*

Malone, K. G. (2018, July 23). Challenges and Opportunities: Climate Change, Rail Talks Bring Both to Churchill, *CBC*.

Malone, K. G. (2020, January 13). Manitoba reserve going to court to demand Ottawa extend flood evacuee benefits, *CTV News*.

Manrique, D. R., Corral, S., & Periera, A. G. (2018). Climate-related displacements of coastal communities in the Arctic: Engaging traditional knowledge in adaptation strategies and policies. *Environmental Science and Policy, 85*, 90-100.

Marché Municipal. (2019). La promenade de la grave à percé: Un littoral distingué. *Marché Municipal*, *14*(1), 18-19.

Markusoff, J. (2018, October 30). In Calgary's Flood Zone, Most Residents Hang On—And Hope the Water Never Rises Again, *Maclean's*.

Marteleira, M. (2017). *Adapting Disaster Risk Reduction Tools to Support Indigenous Resilience: A Case Study in the Strait of Georgia*. Vancouver (BC): University of British Columbia.

Marten, R., Abrassart, T., & Boano, C. (2019). Urban Planning and Natural Hazard Governance. In *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford, United Kingdom: Oxford University Press.

Martin-Moreau, M. & Ménascé, D. (2018). Conditions for success and implementation of resilience strategies. *Field Actions Science Reports*(18).

Mauro, I. (2020). Métis Wildland Firefighters: Connecting with Traditional Land Stewardship. Retrieved July 2021, from https://climateatlas.ca/video/metis-wildland-firefighters.

McCaffrey, S. (2015). Community wildfire preparedness: A global state-of-the-knowledge summary of social science research. *Current Forestry Reports*, *1*(2), 81-90.

McCaffrey, S., McGee, T. K., Coughlan, M., & Tedim, F. (2020). Chapter 8 - Understanding Wildfire Mitigation and Preparedness in the Context of Extreme Wildfires and Disasters: Social Science Contributions to Understanding Human Response to Wildfire. In F. Tedim, V. Leone & T. K. McGee (Eds.), *Extreme Wildfire Events and Disasters*. Cambridge (MA): Elsevier.

McGee, T. K. (2005). Completion of recommended WUI fire mitigation measures within urban households in Edmonton, Canada. *Global Environmental Change Part B: Environmental Hazards, 6*(3), 147-157.

McGee, T. K., McFarlane, B. L., & Varghese, J. (2009). An examination of the influence of hazard experience on wildfire risk perceptions and adoption of mitigation measures. *Society & Natural Resources, 22*(4), 308-323.

McKeown, D. (2015). *Reducing Health Risk from Extreme Heat in Apartment Buildings*. Toronto (ON): City of Toronto.

MECCS (Ministry of Environment and Climate Change Strategy). (2019). *Preliminary Strategic Climate Risk Assessment for British Columbia. Report prepared for the Government of British Columbia*. Victoria (BC): MECCS.

Meckbach, G. (2020, August 31). Adjuster Training: How the Industry Can Up its Game, *Canadian Underwriter*.

Mees, H. & Driessen, P. (2019). A framework for assessing the accountability of local governance arrangements for adaptation to climate change. *Journal of Environmental Planning and Management, 62*(4), 671-691.

Mekis, É., Donaldson, N., Reid, J., Zucconi, A., Hoover, J., Li, Q., . . . Melo, S. (2018). An overview of surface-based precipitation observations at Environment and Climate Change Canada. *Atmosphere-Ocean*, 1-25.

Meyer, C. (2021, February 19). Texas Disaster Shows Need for Climate Audits of Power Grids, Experts Say, *Ottawa Insider*.

Meyer, R. & Kunreuther, H. (2017). *The Ostrich Paradox: Why We Underprepare for Disasters*. Philadelphia (PA): Wharton School Press.

Miami-Dade County. (2021). Property Sale Disclosure. Retrieved March 2021, from https://www.miamidade.gov/environment/flood-disclosure.asp#:~:text=It%20is%20a%20requirement%20of,in%20either%20of%20those%20zones.

Miljure, B. (2020, September 11). Vancouver Air quality Among World's worst Because of U.S. Fires, *CTV News*.

Mitchell, B., Priddle, C., Shrubsole, D., Veale, B., & Walters, D. (2014). Integrated water resource management: Lessons from conservation authorities in Ontario, Canada. *International Journal of Water Resources Development, 30*(3), 460-474.

Mitchell, M. G. E., Schuster, R., Jacob, A. L., Hanna, D. E. L., Dallaire, C. O., Raudsepp-Hearne, C., . . . Chan, K. M. A. (2021). Identifying key ecosystem service providing areas to inform national-scale conservation planning. *Environmental Research Letters, 16*(1), 014038.

MNAI (Municipal Natural Assets Initiative). (2021). About MNAI. Retrieved August 2021, from https://mnai.ca/about/.

MNC (Métis National Council). (2019). Environment Knowledge Place. Retrieved July 2021, from https://environment.metisportals.ca/Menu/.

MNC (Métis National Council). (2021). *Governance.* Ottawa (ON): MNC.

Molnar, M., Olmstead, P., Mitchell, M., Raudsepp-Hearne, C., & Anielski, M. (2021). Chapter 5: Ecosystem Services. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report*. Ottawa (ON): Government of Canada.

Moon, J. & Wallace, K. (2018, June 30). Advocates for Homeless Call for More 24-hour Cooling Centres Amid Heat Wave, *Toronto Star.*

Mora, C., Spirandelli, D., Franklin, E. C., Lynham, J., Kantar, M. B., Miles, W., . . . Hunter, C. L. (2018). Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions. *Nature Climate Change, 8*(12), 1062-1071.

Morrison, A., Noble, B. F., & Westbook, C. J. (2018). Flood risk management in the Canadian prairie provinces: Defaulting towards flood resistance and recovery versus resilience. *Canadian Water Resources Journal, 43*(1), 33-46.

Moudrak, N. & Feltmate, B. (2017). *Preventing Disaster Before It Strikes: Developing a Canadian Standard for New Flood-Resilient Residential Communities.* Waterloo (ON): Intact Centre on Climate Adaptation.

Moudrak, N. & Feltmate, B. (2019). *Weathering the Storm: Developing a Canadian Standard for Flood-Resilient Existing Communities.* Waterloo (ON): Intact Centre on Climate Adaptation.

Moudrak, N. & Feltmate, B. (2020). *Under One Umbrella: Practical Approaches for Reducing Flood Risks in Canada.* Waterloo (ON): Intact Centre on Climate Adaptation.

MPA (Morrison Park Advisors). (2019). *Analysis of Potential Policy Incentives to Support Resilient Towers In Toronto.* Toronto (ON): MPA.

MREM (Ministers Responsible for Emergency Management). (2017). *An Emergency Management Framework for Canada, Third Edition*. Ottawa (ON): Public Safety Canada.

Munich Re. (2017). *Natural Catastrophes 2016.* Munich, Germany: Munich Re.

Munich Re. (2020). Risks Posed by Natural Disasters. Retrieved November 2020, from https://www.munichre.com/en/risks/natural-disasters-losses-are-trending-upwards.html#-1624621007.

Murphy, B., Pearce, L., Chretien, A., & McLean-Purdon, E. (2017). *Mutual Aid and Service Agreements: Wise practices for First Nations Communities*. Ottawa (ON): Indigenous and Northern Affairs Canada.

Narayan, S., Beck, M. W., Wilson, P., Thomas, C. J., Guerrero, A., Shepard, C. C., . . . Trespalacios, D. (2017). The value of coastal wetlands for flood damage reduction in the Northeastern USA. *Scientific Reports*, 7(9463).

NCEI (National Centres for Environmental Information). (2021). Billion-Dollar Weather and Climate Disasters: Overview. Retrieved June 2021, from https://www.ncdc.noaa.gov/billions/overview.

Nemakonde, L. D., van Niekerk, D., & Wentink, G. (2017). National and Sub-National Level Doing Disaster Risk Reduction Including Climate Change Adaptation. In I. Kelman, J. Mercer & J. C. Gaillard (Eds.), *The Routledge Handbook of Disaster Risk Reduction Including Climate Change Adaptation.* London, United Kingdom: Routledge.

Noble, I. R. S. H., Anokhin, Y. A., Carmin, J., Lansigan, D. G. F. P., Osman-Elasha, B., & Villamizar, A. (Intergovernmental Panel on Climate Change). (2014). Adaptation Needs and Options. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, . . . L. L. White (Eds.), *Climate Change 2014: Impacts, Impacts, Adaptation, and Vulnerability.* New York (NY): Cambridge University Press.

Noël, B. (2013). Scientists Warn About Outdated Flood-Risk Maps. Retrieved June 2021, from https://www.cbc.ca/news/canada/new-brunswick/scientists-warn-about-outdated-flood-risk-maps-1.1347199.

Norbury, K. (2013, February 7). Aboriginal Insurance Aims to Fix Native Housing Problem, *The Globe and Mail*.

Northcross, M. (2019). *Rebuild to Fail or Rebuild to Adapt: How CRA Lending Can Guide Climate Change Disaster Response*. San Francisco (CA): Federal Reserve Bank of San Francisco.

NRC (National Research Council of Canada). (2015). *National Plumbing Code of Canada 2015*. Ottawa (ON): NRC.

NRCan (Natural Resources Canada). (2017). Raison D'être, Mandate and Role: Who We Are and What We Do. Retrieved January 2021, from https://www.nrcan.gc.ca/nrcan/transparency/reporting-accountability/plans-performance-reports/raison-detre-mandate-and-role-who-we-are-and-what-we-do/19252.

NRCan (Natural Resources Canada). (2019). Natural Hazards. Retrieved February 2020, from https://www.nrcan.gc.ca/science-and-data/science-and-research/natural-hazards/10657.

NRCan (Natural Resources Canada). (2020a). Canada's Climate Change Adaptation Platform. Retrieved February 2021, from https://www.nrcan.gc.ca/climate-change/impacts-adaptations/adapting-our-changing-climate/10027.

NRCan (Natural Resources Canada). (2020b). Cost of Wildland Fire Protection. Retrieved January 2021, from https://www.nrcan.gc.ca/climate-change/impacts-adaptations/climate-change-impacts-forests/forest-change-indicators/cost-fire-protection/17783.

NRDC (Natural Resources Defense Council). (2012). *Looking Up: How Green Roofs and Cool Roofs Can Reduce Energy Use, Address Climate Change, and Protect Water Resources in Southern California*. New York City (NY): NRDC.

NRTEE (National Roundtable on the Environment and the Economy). (2009). *True North*. Ottawa (ON): NRTEE.

NRTEE (National Round Table on the Environment and the Economy). (2011). *Paying the Price: The Economic Impacts of Climate Change for Canada.* Ottawa (ON): NRTEE.

NYCDCP (New York City Department of City Planning). (2020). *NYC's Floodplain by the Numbers*. New York (NY): NYCDCP.

O'Donoghue, T. & Rabin, M. (1999). Doing it now or later. *American Economic Review, 89*(1), 103-124.

OAG (Office of the Auditor General of Canada). (2018). *Perspectives on Climate Change Action in Canada — A Collaborative Report from Auditors General*. Ottawa (ON): OAG.

OAGO (Office of the Auditor General of Ontario). (2017). Chapter 3, Section 3.04: Emergency Management in Ontario. In *2017 Annual Report*. Toronto (ON): OAGO.

OBWB (Okanagan Basin Water Board). (2021a). What We Do – Overview. Retrieved January 2021, from https://www.obwb.ca/overview/.

OBWB (Okanagan Basin Water Board). (2021b). Projects. Retrieved July 2021, from https://www.obwb.ca/projects/.

OECD (Organisation for Economic Co-operation and Development). (2007). *Awareness and Education on Risk and Insurance Revised Analytical and Comparative Report*. Paris, France: OECD.

OECD (Organisation for Economic Co-operation and Development). (2016a). *Improving the Evidence Base on the Costs of Disasters: Key Findings from an OECD Survey*. Paris, France: OECD.

OECD (Organisation for Economic Co-operation and Development). (2016b). *Financial Management of Flood Risk*. Paris, France: OECD.

OECD (Organisation for Economic Co-operation and Development). (2017a). *National Risk Assessments: A Cross Country Perspective*. Paris, France: OECD.

OECD (Organisation for Economic Co-operation and Development). (2017b). *Behavioural Insights and Public Policy*. Paris, France: OECD.

OECD (Organisation for Economic Co-operation and Development). (2020a). *Nature-based solutions for adapting to water-related climate risks*. Paris, France: OECD.

OECD (Organisation for Economic Co-operation and Development). (2020b). *Linking Indigenous Communities with Regional Development in Canada*. Paris, France: OECD.

OECD & The World Bank (Organisation for Economic Co-operation and Development and The World Bank). (2019). *Fiscal Resilience to Natural Disasters: Lessons from Country Experiences*. Paris, France: OECD.

OFNTSC (Ontario First Nations Technical Services Corporation). (2020). First Nations Infrastructure Resilience Toolkit (FN-IRT). Retrieved October 2021, from https://ofntsc.org/our-services/core-services/operations-and-maintenance/first-nations-infrastructure-resilience.

Ordóñez, C. & Duinker, P. N. (2014). Assessing the vulnerability of urban forests to climate change. *Environmental Reviews, 22*, 311-321.

Oritz, J. L. (2019, December 4). 'Deeply Sorry' PG&E Takes Blame for California's Deadliest Wildfire, Seeks 'Technologies' to Limit Future Risks, *USA Today*.

Orr, A., Migliaccio, C. A. L., Buford, M., Ballou, S., & Migliaccio, C. T. (2020). Sustained effects on lung function in community members following exposure to hazardous PM2.5 levels from wildfire smoke. *Toxics, 8*(3), 53.

OSFI (Office of the Superintendent of Financial Institutions Canada). (2021). *Navigating Uncertainty in Climate Change: Promoting Preparedness and Resilience to Climate-Related Risks*. Ottawa (ON): OSFI.

Oulahen, G., Klein, Y., Mortsch, L., O'Connell, E., & Harford, D. (2018). Barriers and drivers of planning for climate change adaptation across three levels of Government in Canada. *Planning Theory & Practice, 19*(3), 405-421.

Oxfam. (2010). *Gender, Disaster Risk Reduction, and Climate Change Adaptation: A Learning Companion*. Cowly, United Kingdom: Oxfam GB.

Oxfam. (2013). *No Accident: Resilience and the Inequality of Risk*. Cowly, United Kingdom: Oxfam.

Padhy, S. K., Sarkar, S., Panigrahi, M., & Paul, S. (2015). Mental health effects of climate change. *Indian Journal of Occupational and Environmental Medicine, 19*(1), 3-7.

PAGC (Prince Albert Grand Council). (2020). *Overcoming Adversity: Annual Report*. Prince Albert (SK): PAGC Offices.

Palecki, M. A., Changnon, S. A., & Kunkel, K. E. (2001). The nature and impacts of the July 1999 heat wave in the midwestern United States: Learning from the lessons of 1995. *Bulletin of the American Meteorological Society, 82*(7), 1353-1368.

Parsons, P. & BCREA (British Columbia Real Estate Association). (2015). *BC Floodplain Map Inventory Report*. Vancouver (BC): BCREA.

PBO (Office of the Parliamentary Budget Officer). (2016). *Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events*. Ottawa (ON): PBO.

PCC (Prairie Climate Centre). (2019). *Heat Waves and Health: A Special Report on Climate Change in Canada*. Winnipeg (MB): PCC.

PCIC (Pacific Climate Impacts Consortium). (n.d.). BC Station Data. Retrieved June 2021, from https://www.pacificclimate.org/data/bc-station-data.

Penning-Rowsell, E. C., Becker, M. (2019). *Flood Risk Management: Global Case Studies of Governance, Policy and Communities*. London, United Kingdom and New York (NY): Routledge, Taylor and Francis Group.

Pentland, R. & Wood, C. (2013). *Down the Drain: How We are Failing to Protect Our Water Resources*. Vancouver (BC): Greystone Books.

Peter, B. & Wang, S. (2006). Fire Risk and Population Trends in Canada's Wildland–Urban Interface. In K. Hirsch & P. Fuglem (Eds.), *Canadian Wildland Fire Strategy: Background Syntheses, Analyses, and Perspectives.* Ottawa (ON): Canadian Council of Forest Ministers and Natural Resources Canada.

Phillips, C. A., Caldas, A., Cleetus, R., Dahl, K. A., Declet-Barreto, J., Licker, R., . . . Carlson, C. J. (2020). Compound climate risks in the COVID-19 pandemic. *Nature Climate Change, 10*(July 2020), 586-587.

Pielke, R. (2019). Tracking progress on the economic costs of disasters under the indicators of the sustainable development goals. *Environmental Hazards, 18*(1), 1–6.

PIEVC (Public Infrastructure Engineering Vulnerability Committee). (n.d.). PIEVC Protocol. Retrieved June 2021, from https://pievc.ca/protocol/.

Pinchot, A. C., Giulia. (2019). *What Investors Want from Sustainability Data*. Washington (DC): World Resources Institute.

PMO (Office of the Prime Minister). (2019a). Minister of Public Safety and Emergency Preparedness Mandate Letter. Retrieved March 2020, from https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-public-safety-and-emergency-preparedness-mandate-letter.

PMO (Office of the Prime Minister). (2019b). Minister of Environment and Climate Change Mandate Letter. Retrieved March 2020, from https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-environment-and-climate-change-mandate-letter.

PMO (Office of the Prime Minister). (2019c). Minister of Natural Resources Mandate Letter. Retrieved March 2020, from https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-natural-resources-mandate-letter.

PMO (Office of the Prime Minister). (2020). Prime Minister Announces Additional Support for Businesses to Help Save Canadian Jobs. Retrieved February 2020, from https://pm.gc.ca/en/news/news-releases/2020/05/11/prime-minister-announces-additional-support-businesses-help-save.

Porter, J. J. & Dessai, S. (2017). Mini-me: Why do climate scientists' misunderstand users and their needs? *Environmental Science & Policy,* 77, 9-14.

Porter, K., Dash, N., Huyck, C., Santos, J., Scawthorn, C., Eguchi, M., . . . Cohen-Porter, A. (2019). *Natural Hazard Mitigation Saves: 2019 Report.* Washington (DC): Multi-Hazard Mitigation Council, National Institute of Building Sciences.

Porter, K. & Scawthorn, C. (2020). *Estimating the Benefits of Climate Resilient Buildings and Core Public Infrastructure (CRBCPI).* Toronto (ON): Institute for Catastrophic Loss Reduction.

Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., . . . Weyer, N. M. (2019). Technical Summary. In H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, . . . N. M. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Geneva, Switzerland: International Panel on Climate Change.

PRA (Bank of England Prudential Regulation Authority). (2015). *The Impact of Climate Change on the UK Insurance Sector.* London, United Kingdom: PRA.

Press, J. (2017). Documents Show Many Cities Wary of Mapping, Publicizing Flood Risks. Retrieved June 2021, from https://ottawacitizen.com/news/documents-show-many-cities-wary-of-mapping-publicizing-flood-risks.

Prior, T. & Eriksen, C. (2013). Wildfire preparedness, community cohesion and social–ecological systems. *Global Environmental Change, 23*(6), 1575-1586.

PS (Public Safety Canada). (2007). *Guidelines for the Disaster Financial Assistance Arrangements.* Ottawa (ON): PS.

PS (Public Safety Canada). (2012). *All Hazards Risk Assessment Methodology Guidelines 2012–2013*. Ottawa (ON): PS.

PS (Public Safety Canada). (2017a). *2016-2017 Evaluation of the Disaster Financial Assistance Arrangements*. Ottawa (ON): PS.

PS (Public Safety Canada). (2017b). Disaster Assistance Programs - Federal Programs by Topic. Retrieved December 2020, from https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/dsstr-ssstnc-prgrms/dsstr-ssstnc-prgrms-tpc-en.aspx.

PS (Public Safety Canada). (2019a). Canadian Disaster Database. Retrieved March, 2020, from https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx.

PS (Public Safety Canada). (2019b). Disaster Financial Assistance Arrangements (DFAA). Retrieved January 2020, from https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/dsstr-fnncl-ssstnc-rrngmnts/index-en.aspx.

PS (Public Safety Canada). (2019c). About Public Safety Canada. Retrieved January 2021, from https://www.publicsafety.gc.ca/cnt/bt/index-en.aspx.

PS (Public Safety Canada). (2020a). *Departmental Results Report 2019-2020*. Ottawa (ON): PS.

PS (Public Safety Canada). (2020b). Government of Canada Creates Task Force on Flood Insurance and Relocation. Retrieved December 2020, from https://www.canada.ca/en/public-safety-canada/news/2020/11/government-of-canada-creates-task-force-on-flood-insurance-and-relocation.html.

PS (Public Safety Canada). (2020c). *Evaluation of the National Disaster Mitigation Program*. Ottawa (ON): PS.

PS (Public Safety Canada). (2021). National Disaster Mitigation Program (NDMP). Retrieved August 2021, from https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-en.aspx.

Puxley, C. (2015, December 21). Nearly Half of Canada's First Nation Reserves Have 'Little to No' Fire Protection: Report, *The Canadian Press*.

PWGSC (Public Works and Government Services Canada). (2020). Bid on Opportunities. Retrieved January 2021, from https://buyandsell.gc.ca/for-businesses/selling-to-the-government-of-canada/bid-on-opportunities.

Quigley, K., Bisset, B., & Bryan Mills, B. (2017). *Too Critical to Fail: How Canada Manages Threats to Critical Infrastructure*. Kingston (ON): McGill-Queen's Press.

Raikes, J. & McBean, G. (2017). Institutional response to disaster risk: The City of Vancouver and District of Maple Ridge, British Columbia, Canada. *Regional Environmental Change*, *17*, 2433-2441.

RCN (Resilient Cities Network). (2021). Resilient Cities Network. Retrieved March 2021, from https://resilientcitiesnetwork.org/.

RCNNDA (Royal Commission into National Natural Disaster Arrangements). (2020). *Royal Commission into National Natural Disaster Arrangements Report*. Canberra, Australia: Government of Australia.

Ready. (2021). Community Emergency Response Team. Retrieved July 2021, from https://www.ready.gov/cert.

Reed, G., Brunet, N. D., & Natcher, D. C. (2020). Can Indigenous community-based monitoring act as a tool for sustainable self-determination? *The Extractive Industries and Society, 7*(4), 1283-1291.

Righter, D. (2021). From Groundwork to Implementation: A Systematic Review of Coastal Adaptation Planning in Nova Scotia, Canada. Vancouver (BC): University of British Columbia.

Rijke, J., Van Herk, S., Zevenbergen, C., & Ashley, R. (2012). Room for the River: Delivering integrated river basin management in the Netherlands. *International Journal of River Basin Management, 10*(4), 369-382.

RNPN, FEMA, & NOAA (Resilient Nation Partnership Network, Federal Emergency Management Agency, National Oceanic and Atmospheric Administration). (2021). *Building Alliances for Equitable Resilience*. Washington (DC): RNPN, FEMA, and NOAA.

Rockefeller Foundation & ARUP. (2014). *City Resilience Framework*. New York (NY): Rockefeller Foundation.

Roy, P., Fournier, E., & Huard, D. (2017). *Standardization Guidance for Weather Data, Climate Information and Climate Change Projections*. Montreal (QC): Ouranos.

RSA Canada (Royal & Sun Alliance Insurance Company of Canada). (2021). WWF-Canada: Collaborating for Climate Resilient Communities. Retrieved July 2021, from https://www.rsagroup.ca/about-us/corporate-responsibility/wwf-canada-collaborating-climate-resilient-communities.

Rutledge, A. (2017). Re-imagining the Shoreline: Opportunities for Managed Retreat, *HazNet*.

Sandink, D., Kovacs, P., Oulahen, G., & McGillivray, G. (2010). *Making Flood Insurable for Canadian Homeowners: A Discussion Paper*. Toronto (ON): Institute for Catastrophic Loss Reduction & Swiss Reinsurance Company Ltd.

Sankey, S. (2018). *Blueprint for Wildland Fire Science in Canada (2019–2029)*. Edmonton (AB): Natural Resources Canada.

Santé Montréal. (2019). Extreme Heat: 66 Deaths in Montreal in 2018. Retrieved August 2021, from https://santemontreal.qc.ca/en/public/coronavirus-covid-19/news/news/extreme-heat-66-deaths-in-montreal-in-2018/.

Sanusi, R., Johnstone, D., May, P., & Livesley, S. J. (2016). Street Oorientation and side of the street greatly influence the microclimatic benefits street trees can provide in summer. *Journal of Environmental Quality, 45*, 167-174.

Sauchyn, D., Davidson, D., & Johnston, M. (2020). Chapter 4: Prairie Provinces. In F. J. Warren, N. Lulham & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Regional Perspectives Report*. Ottawa (ON): Government of Canada.

Saunders-Hastings, P., Bernard, M., & Doberstein, B. (2020). *Planned Retreat Approaches to Support Resilience to Climate Change in Canada.* Ottawa (ON): Natural Resources Canada.

Sawyer, D., Ness, R., Clark, D., & Beugin, D. (2020). *Tip of the Iceberg: Navigating the Known and Unknown Costs of Climate Change for Canada*. Ottawa (ON): Canadian Institute for Climate Choices.

SCC (Standards Council of Canada). (2018). Northern Infrastructure Standardization Initiative (NISI). Retrieved March 2019, from https://www.scc.ca/en/nisi.

SCC (Standards Council of Canada). (2019a). *Gender and Standardization Strategy 2019-2025*. Ottawa (ON): SCC.

SCC (Standards Council of Canada). (2019b). *Standards to Support Climate Resilience in Infrastructure: Taking stock and mapping the future*. Ottawa (ON): SCC.

SCC & Manifest Climate (Standards Council of Canada). (2021). *Guide for Integrating Climate Change Adaptation Considerations into Canadian Standards*. Ottawa (ON): SCC.

Schardong, A., Simonovic, S. P., Gaur, A., & Sandink, D. (2020). Web-based tool for the development of intensity duration frequency curves under changing climate at gauged and ungauged locations. *Water 12*, 1-31.

Scheyder, E. & Seba, E. (2017, August 27). Harvey Throws a Wrench Into U.S. Energy Engine, *Reuters*.

Schwab, J. C. (2019). Planning Systems for Natural Hazard Risk Reduction. In *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford, United Kingdom: Oxford University Press.

Scott, J. C., Cabello-Llamas, D., & Bittner, P. (2012). *Engaging Indigenous Peoples in Disaster Risk Reduction*. New York (NY): United Nations Permanent Forum on Indigenous Issues.

SDG&E (San Diego Gas & Electric Company). (2020). *Wildfire Mitigation Plan*. San Diego (CA): SDG&E.

Shauffler, F. M. (2014). *Municipal Climate Change Adaptation around the Bay of Fundy: Status and Needs*. Gulf of Maine Council on the Marine Environment.

Shaw, A., Satija, N., & Collier, K. (2016). Boomtown, Flood Town. Retrieved March 2021, from https://www.propublica.org/article/boomtown-flood-town-text.

Shrubsole, D., Brooks, G., Halliday, R., Haque, E., Kumar, A., Lacroix, J., . . . Simonovic, S. P. (2003). *An Assessment of Flood Risk Management in Canada*. Toronto (ON): Institute for Catastrophic Loss Reduction.

Shughart, W. F. I. (2011). Disaster relief as bad public policy. *The Independent Review, 15*(4), 519-539.

Siders, A. (2013). *Managed Coastal Retreat: A Legal Handbook on Shifting Development Away from Vulnerable Areas*. New York (NY): Columbia Center for Climate Change Law.

Slezak, M. (2013, January 16). Australian Inferno Previews Fire-Prone Future, *New Scientist*.

Spak, S. (2005). The position of Indigenous knowledge in Canadian co-management organizations. *Anthropologica, 47*(2), 233-246.

Spalding, M. D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L. Z., Shepard, C. C., & Beck, M. W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management*, 50-57.

Spannagel, E. (2021). Record Canada Heat Harms Older People and People with Disabilities. Retrieved August 2021, from https://www.hrw.org/news/2021/07/09/record-canada-heat-harms-older-people-and-people-disabilities.

St Amour-Gomes, S., Heldsinger, N., & Peddle, S. (2018). *Flood Risk Reduction in Canada: The Road to Becoming a Trusted Source for Preparedness Information*. Waterloo (ON): Partners for Action and the Canadian Red Cross.

St. John, J. (2019, October 15). California Governor Calls for Customer Rebates in Wake of PG&E Blackouts, *Green Tech Media*.

Stacey, J. (2019, June 13). Tsilqot'in Nation Addresses Climate Disasters, *The Conversation*.

Stafford, R., Chamberlain, B., Clavey, L., Gillingham, P. K., McKain, S., Morecroft, M. D., . . . Watts, O. (2021). *Nature-based Solutions for Climate Change in the UK: A Report by the British Ecological Society.* London, United Kingdom: The British Ecological Society.

Stantec. (2019). *First Nations Infrastructure Resilience Toolkit: Development & Pilot Projects.* Ottawa (ON): Stantec.

StatCan (Statistics Canada). (1998). 1996 Census: Aboriginal data. Retrieved July 2021, from https://www150.statcan.gc.ca/n1/daily-quotidien/980113/dq980113-eng.htm.

StatCan (Statistics Canada). (2015). Chart 1: Population Counts by Aboriginal Identity, 2006. Retrieved July 2021, from https://www150.statcan.gc.ca/n1/pub/89-645-x/2010001/c-g/c-g001-eng.htm.

StatCan (Statistics Canada). (2016). Canadians' Experiences with Emergencies and Disasters, 2014. Retrieved July 2021, from https://www150.statcan.gc.ca/n1/pub/85-002-x/2016001/article/14469-eng.htm.

StatCan (Statistics Canada). (2019). Focus on Geography Series, 2016 Census. Retrieved July 2021, from https://www12.statcan.gc.ca/census-recensement/2016/as-sa/fogs-spg/Facts-CAN-eng.cfm?Lang=Eng&GK=CAN&GC=01&TOPIC=9.

Steelman, T. A. & McCaffrey, S. (2013). Best practices in risk and crisis communication: Implications for natural hazards management. *Natural Hazards, 65*(1), 683-705.

Stern, J. (2020, August 21). Two Disasters Are Exponentially Worse Than One, *The Atlantic*.

Stevens, M. R. & Hanschka, S. (2014). Municipal flood hazard mapping: The case of British Columbia, Canada. *Natural Hazards, 73*, 907-932.

Supreme Court of Canada. (2014). Tsilhqot'in Nation v. British Columbia. Retrieved March 2021, from https://scc-csc.lexum.com/scc-csc/scc-csc/en/item/14246/index.do?q=tsilhqot%27in.

Swain, D. L., Singh, D., Touma, D., & Diffenbaugh, N. S. (2020). Attributing extreme events to climate change: A new frontier in a warming world. *One Earth*, 2(6), 522-527.

Swiss Re (Swiss Reinsurance Company Ltd.). (2016). *The Road to Flood Resilience in Canada*. Zurich, Switzerland: Swiss Re.

Swiss Re (Swiss Reinsurance Company Ltd.). (2018). *Closing the Protection Gap. Disaster Risk Financing: Smart Solutions for the Public Sector.* Zurich, Switzerland: Swiss Re.

Swiss Re (Swiss Reinsurance Company Ltd.). (2019). *Natural Catastrophes and Man-Made Disasters in 2018: "Secondary" Perils on the Frontline*. Zurich, Switzerland: Swiss Re.

Swiss Re (Swiss Reinsurance Company Ltd.). (2020). What is Parametric Insurance? Retrieved December 2020, from https://corporatesolutions.swissre.com/insights/knowledge/what_is_parametric_insurance.html.

Swiss Re & GIF (Swiss Reinsurance Company Ltd. and Global Infrastructure Facility). (2021). *Closing the Infrastructure Gap Mobilising Institutional Investment into Sustainable, Quality Infrastructure in Emerging Markets and Developing Economies (EMDEs)*. Zurich, Switzerland: Swiss Re Institute.

Tait, C. (2020, July 11). This Time, Floods May Reshape Fort McMurray, *The Globe and Mail*.

Taylor, K. & Birkland, T. (2019). The Politics and Governance of Mitigation: Considerations for Planning. In M. K. Lindell (Ed.), *The Routledge Handbook of Urban Disaster Resilience: Integrating Mitigation, Preparedness, and Recovery Planning.* Abingdon, United Kingdom: Routledge.

TBS (Treasury Board Secretariat). (2012). *Standard on Geospatial Data*. Ottawa (ON): Government of Canada.

TBS (Treasury Board Secretariat). (2016). Guide to Integrated Risk Management: A Recommended Approach for Developing A Corporate Risk Profile. Retrieved June 2021, from https://www.canada.ca/en/treasury-board-secretariat/corporate/risk-management/guide-integrated-risk-management.html#toc2_1.

TBS (Treasury Board Secretariat). (2020). *Policy on Service and Digital*. Ottawa (ON): Government of Canada.

TCFD (Task Force on Climate-Related Financial Disclosures). (2017). *Recommendations of the Task Force on Climate-related Financial Disclosures*. Basel, Switzerland: TCFD.

TCFD (Task Force on Climate-Related Financial Disclosures). (2020). *Task Force on Climate-related Financial Disclosures Guidance on Risk Management Integration and Disclosure*. Basel, Switzerland: TCFD.

Terpstra, T. & Gutteling, J. M. (2008). Households' perceived responsibilities in flood risk management in The Netherlands. *International Journal of Water Resources Development*, *24*(4), 555-565.

Teufel, B., Diro, G. T., Whan, K., Milrad, S. M., Jeong, D. I., Ganji, A., . . . Sushama, L. (2017). Investigation of the 2013 Alberta flood from weather and climate perspectives. *Climate Dynamics*, *48*(9), 2881-2899.

Teufel, B., Sushama, L., Huziy, O., Diro, G. T., Jeong, D. I., Winger, K., . . . Nguyen, V. T. V. (2019). Investigation of the mechanisms leading to the 2017 Montréal flood. *Climate Dynamics, 52*(7), 4193-4206.

TFRR (Task Force for a Resilient Recovery). (2020). *Bridge to the Future: Final Report from the Task Force for a Resilient Recovery.* TFRR.

THA (Texas Hospital Association). (n.d.). *Texas Hospital Association Hurricane Harvey Analysis.* Austin (TX): THA.

Thaler, R. & Sunstein, C. (2008). *Nudge: The Gentle Power of Choice Architecture*. New Haven (CT): Yale University Press.

Thieken, A. H., Bessel, T., Kienzler, S., Kreibich, H., Müller, M., Pisi, S., & Schröter, K. (2016). The flood of June 2013 in Germany: How much do we know about its impacts? *Natural Hazards and Earth System Sciences, 16*(6), 1519-1540.

Thistlethwaite, J. & Henstra, D. (2017). Municipal flood risk sharing in Canada: A policy instrument analysis. *Canadian Water Resources Journal*, 1–15.

Thistlethwaite, J., Henstra, D., Peddle, S., & Scott, D. (2017). *Canadian Voices on Changing Flood Risk: Findings from a National Survey.* Waterloo (ON): University of Waterloo.

Thistlethwaite, J., Henstra, D., & Ziolecki, A. (2020). *Managed Retreat from High-risk Flood Areas: Design Considerations for Effective Property Buyout Programs*. Waterloo (ON): Centre for International Governance Innovation.

Thomassin, A., Neale, T., & Weir, J. K. (2019). The natural hazard sector's engagement with Indigenous peoples: A critical review of CANZUS countries. *Geographical Research, 57*(2), 164-177.

Thompson, S., Ballard, M., & Martin, D. (2014). Lake St. Martin First Nation community members' experiences of induced displacement: "We're like refugees". *Refuge, 29*(2), 75-86.

TRCA (Toronto and Region Conservation Authority). (2010). *Low Impact Development Stormwater Management Planning and Design Guide*. Toronto (ON): TRCA.

TRCA (Toronto and Region Conservation Authority). (n.d.). Flood Risk Management - History. Retrieved December 2020, from https://trca.ca/conservation/flood-risk-management/history/.

Tsilhqot'in National Government, Gov. of BC, & GC (Government of British Columbia and the Government of Canada). (2018). *Collaborative Emergency Management Agreement*. Victoria (BC): Tsilhqot'in National Government, Gov. of BC, and GC.

Tsui, E. (2021). Reducing Individual Costs of Permafrost Thaw Damage in Canada's Arctic. Retrieved July 2021, from https://www.thearcticinstitute.org/reducing-individual-costs-permafrost-thaw-damage-canada-arctic/.

Tymstra, C., Stocks, B. J., Cai, X., & Flannigan, M. D. (2020). Wildfire management in Canada: Review, challenges and opportunities. *Progress in Disaster Science, 5*, 100045.

U.S. DoE (United States Department of Energy). (2004). *Federal Technology Alert: Green Roofs*. Washington (DC): Energy Efficiency and Renewable Energy.

U.S. National Research Council. (2005). *Naval Analytical Capabilities: Improving Capabilities-Based Planning*. Washington (DC): The National Academies Press.

U.S. National Research Council. (2009). *Informing Decisions in a Changing Climate*. Washington (DC): The National Academies Press.

U.S. National Research Council. (2010). *Informing an Effective Response to Climate Change*. Washington (DC): The National Academies Press.

U.S. National Research Council. (2012). *Disaster Resilience: A National Imperative*. Washington (DC): The National Academies Press.

Uebelein, K., Fyfe, G., Emond, C., Machin, M., Wendling, J., Hutcheson, B., . . . Cunningham, N. (2020). *Companies and Investors Must Put Sustainability and Inclusive Growth at the Centre of Economic Recovery*. AIMCo, BCI, CDPQ, CPP Investments, HOOPP, OMERS, Ontario Teachers', PSP.

UN (United Nations). (2015). *Transforming our World: The 2030 Agenda for Sustainable Development*. New York (NY): UN Publications.

UNCCS (United Nations Climate Change Secretariat). (2017). *Opportunities and Options for Integrating Climate Change Adaptation with the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction 2015–2030*. Bonn, Germany: UNCCS.

UNDRR (United Nations Office for Disaster Risk Reduction). (2016). *Report of the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction*. Geneva, Switzerland: UNDRR.

UNDRR (United Nations Office for Disaster Risk Reduction). (2017). Preserving Heritage Boosts Disaster Resilience. Retrieved July 2021, from https://www.undrr.org/news/preserving-heritage-boosts-disaster-resilience.

UNDRR (United Nations Office for Disaster Risk Reduction). (2019). *Global Assessment Report on Disaster Risk Reduction*. Geneva, Switzerland: UNDRR.

UNFCCC (United Nations Framework Convention on Climate Change). (2015). The Paris Agreement. Retrieved December 2018, from https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

Unger, D. (2020, January 16). Lake St. Martin First Nation Residents Still Waiting To Go Home After Nine Years, *CTV News*.

UNHRC (United Nations Human Rights Council). (2014). *Promotion and Protection of the Rights of Indigenous Peoples in Disaster Risk Reduction, Prevention and Preparedness Initiatives*. Geneva, Switzerland: UNHRC.

UNISDR (United Nations International Strategy for Disaster Reduction). (2008). *Indigenous Knowledge for Disaster Risk Reduction: Good Practices and Lessons Learned from Experiences in the Asia-Pacific Region*. Bangkok, Thailand: UNISDR.

UNISDR (United Nations International Strategy for Disaster Reduction). (2011). *Global Assessment Report on Disaster Risk Reduction: Revealing Risk, Redefining Development. Summary and Main Findings*. Oxford, United Kingdom: UNISDR.

UNISDR (United Nations International Strategy for Disaster Reduction). (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030*. Geneva, Switzerland: UNISDR.

USGCRP (U.S. Global Change Research Program). (2018). *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Washington (DC): USGCRP.

USGS (United States Geological Survey). (n.d.). Post-fire Flooding and Debris Flow. Retrieved February 2021, from https://www.usgs.gov/centers/ca-water/science/post-fire-flooding-and-debris-flow?qt-science_center_objects=0#qt-science_center_objects.

Vargo, J., Stone, B., Habeebc, D., Liu, P., & Russell, A. (2016). The social and spatial distribution of temperature-related health impacts from urban heat island reduction policies. *Environmental Science & Policy, 66*, 366-374.

VBPR (Vancouver Board of Parks and Recreation). (2019). *Vancouver's Parks and Recreation: Strategic Bold Moves*. Vancouver (BC): VBPR.

Verhaeghe, C., Feltes, E., & Stacey, J. (2019). *Nagwediẑk'an Gwaneŝ Gangu Ch'inidẑed Ganexwilagh. The Fires Awakened Us.* Williams Lake (BC): Tsilhqot'in National Government.

Virani Law. (2019). Bylaw Coverage & Rebuilding Your Home. Retrieved July 2020, from https://viranilaw.ca/find-out-how-to-pay-for-bylaw-upgrades-after-an-insurance-loss/.

Vodden, K. & Cunsolo, A. (2021). Rural and Remote Communities. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report*. Ottawa (ON): Government of Canada.

Vogel, B., Henstra, D., & McBean, G. (2020). Sub-national government efforts to activate and motivate local climate change adaptation: Nova Scotia, Canada. *Environment, Development and Sustainability, 22*, 1633-1653.

Waardenburg, M., Groenleer, M., de Jong, J., & Keijser, B. (2020). Paradoxes of collaborative governance: Investigating the real-life dynamics of multiagency collaborations using a quasi-experimental action-research approach. *Public Management Review, 22*(3), 386-407.

Wagner, G. & Weitzman, M. L. (2015). *Climate Shock*. Princeton (NJ): Princeton University Press.

Wang, T., Hamann, A., Spittlehouse, D., Carroll, C. (2016). Locally downscaled and spatial customizable climate data for historical and future periods for North America. *PLoS ONE, 11*(6), e0156720.

Wang, X., Parisien, M.-A., Taylor, S. W., Candau, J.-N., Stralberg, D., Marshall, G. A., . . . Flannigan, M. D. (2017). Projected changes in daily fire spread across Canada over the next century. *Environmental Research Letters, 12*(2), 025005.

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., . . . Costello, A. (2015). Health and climate change: Policy responses to protect public health. *Lancet, 386*(10006), 1861-1914.

WCRP (World Climate Research Programme). (2017). WCRP Coupled Model Intercomparison Project (CMIP). Retrieved March 2021, from https://www.wcrp-climate.org/wgcm-cmip.

WCRP CORDEX (World Climate Research Programme Coordinated Regional Climate Downscaling Experiment). (n.d.-a). About CORDEX, History. Retrieved March 2021, from https://cordex.org/about/history/.

WCRP CORDEX (World Climate Research Programme Coordinated Regional Climate Downscaling Experiment). (n.d.-b). About CORDEX, What is Regional Downscaling? Retrieved March 2021, from https://cordex.org/about/what-is-regional-downscaling/.

Weaver, C. P., Lempert, R. J., Brown, C., Hall, J. A., Revell, D., & Sarewitz, D. (2013). Improving the contribution of climate model information to decision making: The value and demands of robust decision frameworks. *WIREs Climate Change, 4*(1), 39-60.

WEF (World Economic Forum). (2021). *The Global Risks Report 2021, 16th Edition*. Geneva, Switzerland: WEF.

Westra, S., Fowler, H. J., Evans, J. P., Alexander, L. V., Berg, P., Johnson, F., . . . Roberts, N. M. (2014). Future changes to the intensity and frequency of short-duration extreme rainfall. *Reviews of Geophysics, 52*(3), 522-555.

Wharton, K. (2015). Resilient Cities: From Fail-Safe to Safe-to-Fail. Retrieved July 2021, from https://research.asu.edu/resilient-cities-fail-safe-safe-fail.

Whitman, E. (2020). Climate change adaptation for wildland fire and ecosystem management, *Canadian Wildland Fire & Smoke Newsletter.*

WHOI (Woods Hole Oceanographic Institute). (2021). About iFlood. Retrieved February 2021, from https://iflood.whoi.edu/.

Wildfire Partners. (n.d.). Our Program. Retrieved December 2020, from https://wildfirepartners.org/our-program/.

Wilson, N. J., Mutter, E., Inkster, J., & Satterfield, T. (2018). Community-Based Monitoring as the practice of Indigenous governance: A case study of Indigenous-led water quality monitoring in the Yukon River Basin. *Journal of Environmental Management, 210*, 290-298.

World Bank. (2020). Canada. Retrieved March 2020, from https://data.worldbank.org/country/canada.

Worte, C. (2017). Integrated watershed management and Ontario's conservation authorities. *International Journal of Water Resources Development, 33*(3), 360-374.

Wotton, B. M., Flannigan, M. D., & Marshall, G. A. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. *Environmental Research Letters, 12*(9), 095003.

Xwisten Nation, Michel, G., Langlois, B., Eustache, J., Andrew, D., Cardinal Christianson, A., & Caverley, N. (2020). Story #2: Revitalizing Cultural Burning. In FireSmart Canada (Ed.), *Blazing the Trail: Celebrating Indigenous Fire Stewardship*. Sherwood Park (AB): FireSmart Canada.

Yellow Old Woman-Munro, D., Yumagulova, L., & Dicken, E. (2021). *Unnatural Disasters*. Ottawa (ON): Canadian Institute for Climate Choices.

Yumagulova, L., Phibbs, S., Kenney, C. M., Yellow Old Woman-Munro, D., Cardinal Christianson, A., McGee, T. K., & Whitehair, R. (2019). The role of disaster volunteering in Indigenous communities. *Environmental Hazards*, 1-19.

Yumagulova, L., Yellow Old Woman-Munro, D., MacLean-Hawes, A., Naveau, D., & Vogel, B. (2021). *Building Climate Resilience in First Nation Communities*. Preparing Our Home.

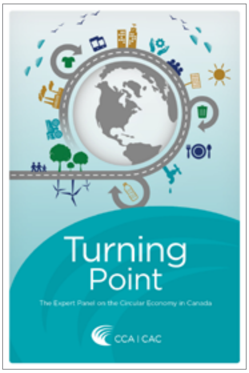
Zahmatkesh, Z., Kumar Jha, S., Coulibaly, P., & Stadnyk, T. (2019). An overview of river flood forecasting procedures in Canadian watersheds. *Canadian Water Resources Journal*, *44*(3), 213-229.

Zevenbergena, C., Rijkeb, J., van Herkb, S., & Bloemenc, P. J. T. M. (2015). Room for the River: A stepping stone in adaptive delta management. *International Journal of Water Governance*(1), 121-140.

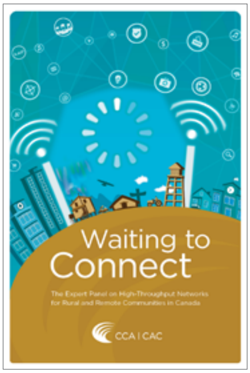
Zhang, X., Flato, G., Kirchmeier-Young, M. C., Vincent, L., Wan, H., Wang, X., . . . Kharin, V. V. (2019). Chapter 4: Changes in Temperature and Precipitation Across Canada. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa (ON): Government of Canada.

CCA Reports of Interest

The assessment reports listed below are available on the CCA's website (www.cca-reports.ca):



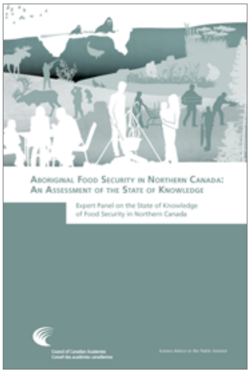
Turning Point
(2021)



Waiting to Connect
(2021)

Canada's Top Climate Change Risks
(2019)

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



Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge
(2014)

Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity
(2013)

CCA Board of Directors*

*As of January 2022

CCA Scientific Advisory Committee*

David Castle (Chair), Professor, School of Public Administration and Gustavson School of Business, University of Victoria; Researcher in Residence, Office of the Chief Science Advisor to the Prime Minister of Canada (Victoria, BC)

Maydianne C. B. Andrade, Professor, Biological Sciences, University of Toronto Scarborough; President, Canadian Black Scientists Network (Toronto, ON)

Peter Backx, FRSC, Professor, Department of Biology, and Canada Research Chair in in Cardiovascular Biology, York University (Toronto, ON)

Stephanie Chang, Professor, School of Community and Regional Planning and Institute for Resources, Environment and Sustainability, University of British Columbia (Vancouver, BC)

Neena L. Chappell, Professor Emeritus, Institute on Aging and Lifelong Health and the Department of Sociology, University of Victoria (Victoria, BC)

Jackie Dawson, Canada Research Chair in Environment, Society and Policy, and Associate Professor, Department of Geography, University of Ottawa (Ottawa, ON)

Colleen M. Flood, FRSC, FCAHS, Director, Centre for Health Law, Policy and Ethics; Professor, Faculty of Law (Common Law Section), University of Ottawa (Ottawa, ON)

Jeffrey A. Hutchings, FRSC, Killam Memorial Chair and Professor of Biology, Dalhousie University (Halifax, NS)

Digvir S. Jayas, O.C., FRSC, FCAE, Distinguished Professor and Vice-President (Research and International), University of Manitoba (Winnipeg, MB)

Malcolm King, FCAHS, Scientific Director, Saskatchewan Centre for Patient-Oriented Research, University of Saskatchewan (Saskatoon, SK)

Chris MacDonald, Associate Professor; Director, Ted Rogers Leadership Centre; Chair, Law and Business Department; Ted Rogers School of Management, Ryerson University (Toronto, ON)

Barbara Neis, C.M., FRSC, John Paton Lewis Distinguished University Professor, Memorial University of Newfoundland (St. John's, NL)

Nicole A. Poirier, FCAE, President, KoanTeknico Solutions Inc. (Beaconsfield, QC)

Jamie Snook, Executive Director, Torngat Wildlife Plants and Fisheries Secretariat (Happy Valley-Goose Bay, NL)

David A. Wolfe, Professor of Political Science, University of Toronto Mississauga; Co-Director, Innovation Policy Lab, Munk School of Global Affairs and Public Policy, University of Toronto (Toronto, ON)

*As of January 2022

Council of Canadian Academies | Conseil des académies canadiennes

180 Elgin Street, Suite 1401
Ottawa ON K2P 2K3
Tel: 613 567-5000
www.cca-reports.ca