TIP OF THE ICEBERG

NAVIGATING THE KNOWN AND UNKNOWN COSTS OF CLIMATE CHANGE FOR CANADA

CANADIAN INSTITUTE FOR CLIMATE CHOICES
INSTITUT CANADIEN POUR DES CHOIX CLIMATIQUES

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The **Canadian Institute for Climate Choices** is an unparalleled collaboration of experts from a diverse range of disciplines and organizations across the country.

As an independent, non-partisan and publicly funded organization, we undertake rigorous and independent research, conduct insightful analysis, and engage a diverse range of stakeholders and rightsholders to bring clarity to the climate challenges and transformative policy choices ahead for Canada. Learn more at climatechoices.ca.

EXECUTIVE SUMMARY

Over the past five decades, the costs of weather-related disasters like floods, storms, and wildfires have risen from tens of millions of dollars to billions of dollars annually in Canada. Insured losses for catastrophic weather events totalled over $18 billlion between 2010 and 2019, and the number of catastrophic events was over three times higher than in the 1980s.

The combined losses per weather-related disaster have also ballooned—rising from an average of $8.3 million per event in the 1970s to an average of $112 million between 2010–2019, including public and private costs. This change represents a staggering 1250 per cent increase.

As climate change makes weather patterns more extreme and volatile, disasters are becoming more frequent and more expensive. In previous decades, the cost of weather-related disasters was roughly equivalent to one per cent of Canada's annual gross domestic product (GDP) growth. In the last decade, disaster costs have climbed to between five and six per cent of annual GDP growth.

These examples offer a snapshot of the ways climate change is threatening economic growth and prosperity across the country today. Yet for everything we know about the current and likely future costs of weather-related disasters in Canada, the risks arising from what we don't yet know—outcomes that depend on too many other variables, or costs we can't fully calculate today—are even more profound.

It's time for a comprehensive reckoning with the costs of climate change in Canada. To that end, the Canadian Institute for Climate Choices (the Institute) is undertaking a multi-year research program to identify and quantify key effects of a changing climate on prosperity in Canada and analyze the benefits of making adaptation and resilience a priority for policy and investment.

If we think of the costs of climate change as an iceberg ahead, this introductory paper aims to zoom in on the tip of the iceberg—the known and measurable hazards—as well as the contours of what lies below the water. As policy makers, business leaders, communities and individuals cope with the current impacts of climate change and prepare for a future defined by climate disruption, both parts of the iceberg should be top-of-mind in risk assessments, investment planning, and policy decisions.

Our analysis of existing data and research finds that climate change is already having noticeable impacts throughout our economy and our society, and those impacts are poised to grow dramatically. The full impacts of climate change will affect Canada in ways that have not yet been properly assessed or considered. Moreover, many climate-related impacts are difficult to quantify in dollar terms but have huge significance for the well-being of Canadians and Indigenous peoples.

INSIGHTS

1 The risk of weather-related disasters in Canada is growing, and climate change is a central force behind increasing damages.

While there have always been weather-related damages and disasters, changing climatic conditions are shifting hazards, driving damages above what we have seen in the past. Decades of insurance payouts and disaster spending by governments, prominent indicators of the cost of weather-related disasters, show a noteworthy rise in both the number of catastrophic events and their costs. Storm and disaster damages are growing faster than the rate of economic or population growth.

2 A changing climate is impairing prosperity and well-being in Canada through economic, social, and environmental impacts. Yet governments, businesses, and communities are overlooking many damages and are not focusing on how to navigate vulnerabilities.

Weather-related disasters and storms are big and visible sources of climate change risk, but these are just the tip of the iceberg. The damages from drawn-out impacts, such as sea-level rise, ocean acidification and permafrost thaw, are equally concerning. The literature signals that climate damages are beginning to grow, affecting the lives and health of people in this country, stretching government resources, exacerbating inequity, and disrupting business operations. Furthermore, many Indigenous communities have articulated damages to ways of life associated with shifting ecosystems, changing wildfire patterns, permafrost thaw, and floods. While there is evidence of growing climate damages and risks to Indigenous rights,[1] and to prosperity and well-being more broadly, there are much larger gaps in knowledge about how best to adapt to a changing climate. Numerous and often overlapping climate change hazards present a major challenge for charting a course to prosperity.

3 Costs that are difficult to quantify in economic terms must not be overlooked.

Not all climate costs are easy or appropriate to measure in economic terms. In particular, emerging economic risks and vulnerabilities will need to be addressed and prioritized for action, even if they can not yet be assigned a monetary value. Further, risks that cannot be given a price tag, such as risks to lands and ecosystems that are integrated into the spiritual lives and identities of Indigenous peoples, must be given at least equal consideration alongside monetary impacts. Our approach to identifying climate-related risks to prosperity and well-being highlights the broad range of impacts to what people and communities across Canada value and then seeks to monetize what is feasible and credible. To provide a comprehensive picture of what a changing climate in Canada may mean, our ongoing work includes quantitative analysis of economic, social, and environmental damages and costs but also highlights a broader scope of impacts beyond what can be quantified in monetary terms.

[1] As Canada is a full supporter of the United Nations Declaration of Indigenous People, it is imperative that Canada ensure Indigenous people participate in decision-making matters that would affect their lands, territories, and resources (Article 18), especially in the context of these risks.

4 Prevention pays off, and governments, businesses, and communities across Canada need to invest more thoughtfully to reduce future climate change damages.

While costs associated with climate change are not fully understood, evidence shows the impacts are getting worse. Approaches that could help manage these risks—from private actions to public policy—remain broadly under-used. Yet experience suggests that prevention pays off, with small investments to reduce vulnerability to climate risks potentially delivering broad-based social, economic, and environmental benefits. Still, damages continue to mount as the changes in extremes and drawn-out climate impacts reduce asset values, impair natural and produced wealth, and increase social vulnerabilities and inequalities. This cycle needs to change. It will pay to continually ask: are risks to household, business, and community value understood? Is planning and investment oriented to build resilience at a scope and scale that is aligned with the evolving climate risks?

5 A successful pathway to climate change resilience requires embracing incomplete information.

All orders of government, all sectors, and all communities need to take action to prioritize resilience to the emerging impacts of climate change. Building resilience requires moving forward with addressing vulnerabilities and investing in solutions despite imperfect information about the impending climate change costs. The debate about whether and how to prioritize adaptive responses to climate change is not informed by reliable information. It's essential to transition from a state of ad hoc responses to a changing climate and weather-related disasters to one of building resilience. This includes continual learning about what works, what doesn't, and how to plan for uncertainty. Instead of waiting for more information, the uncertainty inherent in climate change requires acting decisively on what we already know while also developing improved foresight.

The imperative to reduce greenhouse gas emissions tends to dominate the debate over Canada's progress in addressing climate change. Yet, as a climate solution, adaptation—ensuring human and natural systems can adjust to the spectrum of effects of climate change—will have a critical impact on the well-being and prosperity of all who live in Canada in the decades ahead.

Current adaptation policies and investments in Canada fall far short of what is needed to address the known risks of climate change, let alone those that are still unclear and unknown. This has to change.

RECOMMENDATIONS

Governments, businesses and communities must get serious about putting adaptation policies and practices into place now, while better identifying the physical and social climate risks threatening well-being and future prosperity. The following policy recommendations provide a starting point:

1 All orders of government should significantly scale up public funding for implementing adaptation.

A lack of foresight on climate change risks should not be a barrier to significantly scaling up adaptation investment. Addressing climate-related risk and building resilience implicates many, if not most, government activities and programs. Successful implementation therefore requires not only dedicated government capacity and expertise on adaptation, but mechanisms to integrate and fund adaptation in existing government programs and public investments, including infrastructure, health care, Indigenous affairs, Northern programs, economic development, energy, public safety, natural resource management, and environmental protection. To drive this change, government programs and investments should transparently evaluate their effects on current and future climate risks, and the costs and benefits of incorporating adaptation and resilience. As our analysis shows, adaptation faces barriers to implementation, but returns multiple benefits.

2 The federal government should convene provincial, territorial, Indigenous and municipal governments to co-develop a more coordinated approach to governing adaptation.

The need to deploy adaptation at the scale and speed that Canada requires transcends administrative, geographic, and sectoral boundaries. Adaptation must be tailored and implemented at a local level to reflect local context. Yet coordination can reduce overlap, inconsistencies, and gaps. A coordinated, collaborative approach could set adaptation priorities, goals, and measures of progress, establish roles and responsibilities, identify policies that are essential for driving adaptation at all scales, and coordinate and leverage finance.

3 Governments and financial regulators should systematically enhance public disclosure and transparency of the economic and social implications of climate change risks across both the public and private sectors.

As the Task Force on Climate-Related Financial Disclosures and Canada's Expert Panel on Sustainable Finance have highlighted, transparency about climate change risks is essential for allocating investment away from risk and towards resilience. This extends beyond disclosure rules for large, publicly traded companies; it also includes increased transparency around the climate risks that governments, communities, and individuals face. Whether incorporated into government credit ratings or real estate home inspections, this information will help governments, firms, and individuals better prepare for a changing climate. It will also shift investments toward resilient solutions, galvanizing a range of adaptation actions.

The Institute's ongoing research into the costs of climate change aims to bring clarity to both what we know about the changes ahead and what we don't. Our analysis will highlight the need to plan and design for a changing climate in how Canadians build, work, and live—even in the midst of uncertainty and imperfect information. And we will provide practical advice to governments regarding policies and investments that can mobilize smart adaptation across our economy and across the country.

Policy and investment decisions need to account for today's known costs that form the tip of the iceberg, as well as the less clear hazards that lurk below the surface. While the sheer scale of the threats ahead is daunting, improving foresight while also acting on the knowledge available today provides the chance to course correct en route to a resilient and prosperous future.

Over the next two years, our research into the costs of climate change will expand on and support these recommendations.

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Three ways governments should make climate change a national priority:

Dramatically scale up public investment in adaptation, given economic and other benefits.

Work with other governments in Canada to improve efficiency and coordination.

Systematically enhance disclosure of physical climate risks to mobilize planning and investment decisions.

The uncertainty inherent in climate change requires acting decisively on what we already know while also developing improved foresight.

INTRODUCTION

Public and private-sector decision-making has yet to fully reflect climate-related risks. Multiple factors underpin that failure, but here's one important one: the scale and urgency of action on climate change adaptation in Canada is limited by the absence of a current and comprehensive understanding of the future costs and risks associated with climate change.

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Policy and investment decisions need to account for today's known costs that form the tip of the iceberg, as well as the less clear hazards that lurk below the surface. While the sheer scale of the threats ahead is daunting, improving foresight while also acting on the knowledge we have today provides the chance to course correct en route to a resilient and prosperous future.

Over the next two years, research undertaken by the Canadian Institute for Climate Choices (the Institute) into the costs of climate change will expand on and support these recommendations.

This report is the Institute's first step toward filling that information gap. If the costs of climate change represent an iceberg on the horizon, there is value in assessing how big the iceberg is and how big a risk it poses. That exercise can inform planning and investment priorities for households, businesses, and governments. It can guide private decisions and policy action to help manage climate risks. And it can identify uncertainties that need more attention, such as how weather and climate are changing in unpredictable and increasingly destructive ways.

At the same time, we recognize that a lack of information is not the main reason Canada—along with the rest of the world—remains on a collision course with the iceberg. There are already extensive evidence and warning signs. Canada's immediate priority must be to course correct to reduce damage from the profound costs ahead, irrespective of exactly how large they might be or their root cause, while continuing to improve the accuracy of medium- and long-term predictions.

Governments and researchers around the world are actively developing national-scale estimates of the economic and social costs of climate change.

Indigenous peoples in Canada, including First Nations, Inuit and Métis peoples, have long been adapting to changing environmental conditions. Indigenous knowledge systems and Western research can provide significant insights into the potential costs of climate change in Canada.

Yet Canada lacks up-to-date evidence on the potential economic impacts of climate change. In 2011, the National Round Table on the Environment and the Economy developed the report *Paying the Price: The Economic Impacts of Climate Change for Canada*.[2] Since then, no other studies have built on this initial effort to examine a broad range of costs at a national scale.

To fill this gap, the Institute is analyzing the economic implications of climate change for Canada. This research series aims to contribute substantially to quantifying foreseeable climate-related impacts and their potential costs. It will also illustrate how adaptation at a national scale can help to reduce these costs. However, given the current gaps in knowledge, data and analytical tools, our results should be considered a lower-bound or conservative estimate of the anticipated future costs of climate change. The full scope of economic implications of climate change in Canada is even larger.

This fact has two big implications: first, that a major investment is required to fill the considerable gaps in the understanding of climate change risks in Canada and social, economic, and environmental vulnerabilities. And second, that the challenge looms so large that Canada needs to move adaptation to the top of the agenda and immediately scale up efforts to reduce climate-related risk and build resilience.

Reducing emissions alone isn't enough to put governments, businesses, and communities in Canada on track to address climate change while building a more equitable and prosperous future. Adaptation is the critical missing link.

This first report offers an introduction to the significance of the costs of climate change in Canada, as a foundation for the rest of the research series. Data on the history of weather-related disasters in Canada illustrates the scale, speed, and pervasiveness with which climate change and a lack of climate adaptation are impacting—and will continue to impact—national, regional, and local economies. Surveying existing literature and analysis provides a more comprehensive overview of the types of climate change costs that can be expected in the future in Canada. We consider how an array of choices can affect the nature of these risks and how adaptation investments can improve resilience. Finally, we explore key steps to move toward a resilient, prosperous future.

We recommend that governments should make climate change adaptation a national priority by:

1. **Dramatically scaling up public investment in adaptation**, given the economic and other benefits it offers;
2. **Working with other orders of government in Canada** to improve the efficiency and coordination of adaptation policies and implementation; and
3. **Systematically enhancing disclosure of physical climate risks** to mobilize planning and investment decisions across governments, firms, and individuals.

[2]Some staff and advisors of the Canadian Institute for Climate Choices contributed to the development of the National Round Table on the Environment and the Economy's 2011 report *Paying the Price*.

Our research into the costs of climate change over the next two years will expand on and support these recommendations. That research includes the following reports:

2021

HEALTH REPORT
SPRING 2021

A closer look at health costs and adaptation opportunities, built around our analysis of the costs of climate-driven heat-linked health burdens, Lyme disease and air quality changes. The report will also include case studies on health impacts related to forest fires and a discussion of mental health impacts.

INFRASTRUCTURE REPORT
SUMMER 2021

A focused report on infrastructure costs and adaptation opportunities, built around our analysis of climate-induced impacts to flooding, transportation infrastructure, electricity systems, to flooding, transportation infrastructure, and electricity systems.

NORTHERN REPORT
FALL 2021

Taking a deeper dive into how climate change is affecting Northern infrastructure and buildings, this report will explore the breadth and scale of impacts on communities and the land across the North—impacts that economic studies often underemphasize or leave out.

MACROECONOMIC REPORT
LATE 2021–EARLY 2022

Using national macroeconomic modelling of potential climate change impacts to vulnerable sectors and assets, this report will outline the implications of a changing climate on economic productivity and well-being.

2022

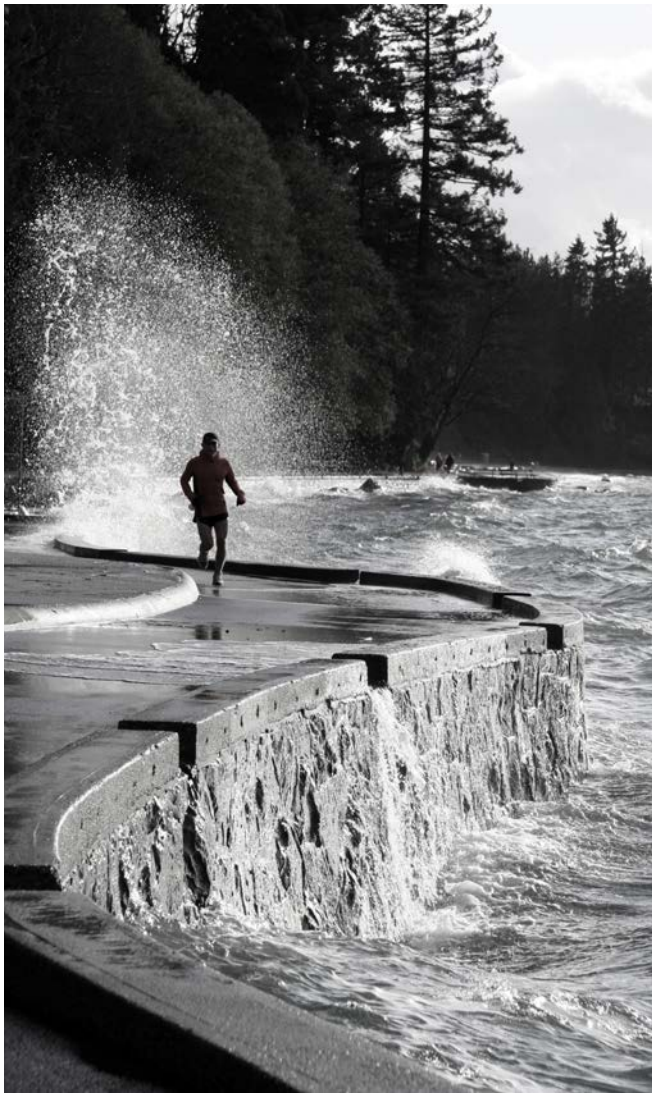
THE **LOOMING COSTS** OF CLIMATE CHANGE

A comprehensive view of the costs and benefits of climate change must consider projected changes in climate hazards—both extreme events and slow-onset changes—and evaluate their impact on social, economic, and environmental systems that are vulnerable to change. Climate change risk isn't static over time; it can increase or decrease along with the changing exposure and vulnerability of households, communities, and industries to climate hazards. Many non-climate factors, such as decisions to build in areas susceptible to flooding or wildfires, also contribute to risk.

Climate change costs can manifest directly—for example, as expenditures made to fix or replace infrastructure that is damaged. Weather-related disasters are another direct and very visible climate change cost, triggering catastrophic losses to property and reducing income. Less visible climate change costs can occur indirectly through, for example, business interruption costs associated with transportation delays when highways are impassable after a flood. There are still other less tangible but important costs—such as impacts on human health and quality of life, loss of spiritually and culturally important lands, and destruction of ecosystems and their function.

Not all aspects of climate change will necessarily result in economic costs and losses. Benefits may stem from changes in climate that trigger, for example, longer growing seasons or reductions in the need to heat buildings in cold seasons. However, forecasts of potential economic benefits of climate change in Canada need to be treated with caution, as they are often based on highly simplified information. For example, projections of the benefits to the agricultural sector of longer growing seasons in a changing climate may not consider the impacts of more frequent spring floods and summer droughts that will also occur (Climate Atlas of Canada, 2020).

Canada is lagging significantly behind the U.S. and other OECD countries in these assessments and thus lacks an understanding of the economic implications that are essential to setting climate action priorities.



Research by governments and scholars provide a broad body of knowledge on climate hazards in Canada and the physical and monetary risks to the country's economic, social, and environmental systems. However, comprehensive information about Canadian costs is limited. A thorough assessment of costs and benefits of climate change requires the identification and monetization of the positive and negative impacts of a full range of climate change impacts on economic, environmental, and social systems. Canada is lagging significantly behind the U.S. and other OECD countries in these assessments and thus lacks an understanding of the economic implications that are essential to setting climate action priorities. Our research on the costs of climate change in Canada will begin to fill this gap.

To identify climate change risks with major economic implications that would be the focus of the research, we analyzed a range of climate hazards to which Canada could be exposed in the coming decades, drawing on national and regional climate science syntheses and risk studies (e.g., CCA, 2019; ECCC, 2019; Palko and Lemmen, 2017; Warren and Lemmen, 2016). At the same time, we analyzed the literature on the economic implications of climate change, often drawing on studies from peer countries, to map the state of knowledge on climate change costs and understand what can and can't be practically and credibly quantified in monetary terms. The result is a picture of the costs of climate change in Canada and a clearer idea of potentially catastrophic impacts lurking below the waterline. Figure 1 shows examples of the current spectrum of understanding, from risks that are well understood and for which we can credibly predict costs, to those that are possible but whose scale and timing is impossible to predict, let alone monetize.

Three key insights emerge from our survey of existing research:

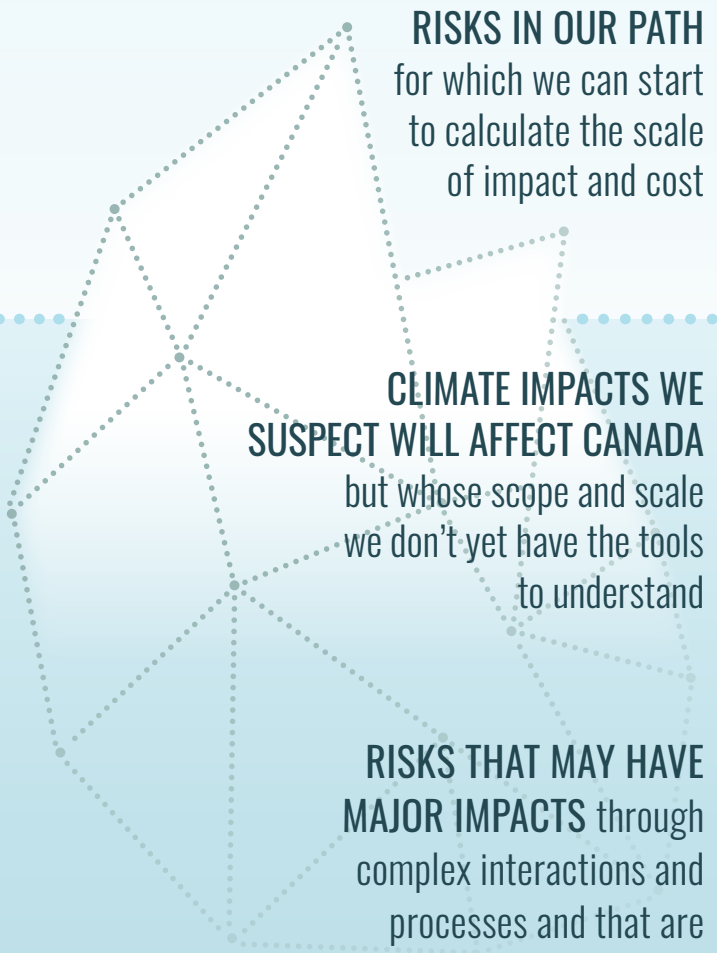
- **No region or sector seems to be immune to the damages of climate change**. Climate change risks are pervasive, with multiple climate hazards that could trigger a broad spectrum of economic, environmental, and social costs. Some regions are more susceptible to particular types of hazards that will be exacerbated by climate change—notably Northern communities impacted by the rapid degradation of infrastructure due to permafrost thaw.
- **Risks are cross-cutting and compounding and more acute for vulnerable groups.** Climate change risks are exacerbated by policies and programs that make people, economies, and ecosystems more vulnerable. Cross-cutting climate change risks interact with one another and are compounding existing vulnerabilities. For example, Northern communities are also predominantly Indigenous communities, and are thus at greater risk from the combination of drastic Northern climate change and socio-economic vulnerability that is the legacy of racist colonial policies.
- **Available knowledge only reflects the tip of the iceberg.** There are important gaps in our knowledge about potential damages that exacerbate climate-related risks. Some costs we can see—notably the costs of weather-related disasters. Yet, cost estimates and methods to monetize associated damages are not available for a wide range of risks to Canadian prosperity. Any estimates of damages using currently available data and tools will inevitably be incomplete and likely represent the lower bound of expected impacts.

The next section explores the most visible category of climate change costs: weather-related disasters. The subsequent section surveys the literature on the costs of climate change in Canada, providing an overview of the types of costs Canada has experienced so far, and a snapshot of what we can expect in the future.

FIGURE 1

THE CLIMATE COSTS **ICEBERG**

Climate change is bringing new threats onto Canada's horizon while amplifying existing hazards. A small number of the risks that Canadian households, communities, and businesses face are well understood. Many other risks are looming under the surface—researchers don't know yet how the risks will change over time or how they may interact with other social, environmental, and economic systems. Faced with this uncertainty, decision makers—and individuals—need to avoid the trap of inaction and instead adaptively manage these risks.



RISKS IN OUR PATH
for which we can start to calculate the scale of impact and cost

- Destruction to homes and communities from floods and sea level rise
- Worsening Northern housing shortages due to damage from permafrost thaw
- Increase in the number of deaths and hospital visits due to heatwaves

CLIMATE IMPACTS WE SUSPECT WILL AFFECT CANADA
but whose scope and scale we don't yet have the tools to understand

- Impacts on human health and wellbeing from wildfires
- Disruption to business and critical supply chains from severe weather events and disasters
- Impacts of climate-change-related damages on investment returns and household finances

RISKS THAT MAY HAVE MAJOR IMPACTS through complex interactions and processes and that are very challenging to predict

- International conflict and migration influenced by climate impacts on global geopolitical and economic stability
- Interactions of multiple hazards that occur simultaneously or in rapid succession, such as sea-level rise and permafrost thaw impacts to Northern coastal communities
- Cascading impacts from damage to critical systems, such as loss of electricity and communications systems at the same time as a wildfire evacuation

DISASTERS ON THE RISE: CATASTROPHIC LOSSES AND COSTS

Climate-related disasters and the associated damages are among the most visible indicators of the costs of climate change. Yet, these costs provide an incomplete picture since they do not represent the full range of social, economic, and environmental damages of climate change. Still, ongoing catastrophic losses and disaster costs in Canada are the very visible tip of the climate costs iceberg.

The private sector covers some catastrophic losses to property through insurance, while the public sector, at all levels, spends on weather-related disaster response and recovery. These costs are reasonably easy to calculate, reflecting the sum of market transactions by private insurers and governments. Adding to these weather-related disaster costs are uninsured losses to property and lost income for households and businesses.

There are also less tangible weather-related costs stemming from impacts on ecosystem function and mental health, for example. Currently, it is the insured losses and government payments that are typically reported for weather-related disasters, with little accounting and reporting of other losses. The data on weather-related disaster costs, therefore, provide a highly incomplete view of the total costs.

Still, historical data since the 1970s points to a growing threat that disaster costs and catastrophic losses are becoming larger and more frequent relative to past events. Notably, as we explore in this section, catastrophic insured losses and disaster costs have risen from tens of millions of dollars to billions of dollars annually, even when correcting for an expanding economy, more valuable assets, and a growing population.

Not all weather-related disaster costs should be attributed to a changing climate, but evidence suggests that climate change is increasingly altering weather and climate patterns, resulting in higher damages than historically observed. Other major contributors to growing disaster costs include an expanding economy, an expanding population pushing into areas more exposed to weather disasters, loss of natural infrastructure, and aging municipal infrastructure and housing.

In a sense, the extent to which climate change has contributed to the total weather-related disaster costs does not matter. Trends indicate that vulnerability in Canada to weather-related disasters is climbing due to several compounding factors, including climate change. We return to this discussion later in this chapter.

Weather-related disasters and costs on the rise

While weather-related disasters have always occurred in Canada, it is clear from data that something is going on with respect to their number and costs. This section uses two separate datasets to assess trends in the number of disasters and their costs:

- **The Canadian Disaster Database (CDD).** Since 1970, the federal government's Disaster Financial Assistance Arrangements (DFAA) program has backstopped provinces, territories, and individuals in covering the costs of disasters. As part of the program, the CDD tracks the most significant weather-related hazards, in terms of frequency, cost, and people evacuated. Costs include include some insured and uninsured catastrophic losses. Disaster costs totalled $35 billion[3] for 300 of the 645 weather-related disasters recorded since 1970. The most frequently reported weather-related disasters include floods, with 40 per cent of the total number, followed by severe thunderstorms (18 per cent), wildfires (15 per cent), and winter storms (nine per cent).[4] Hail, wind, and ice events are included in these categories.

- **Insurance Bureau of Canada (IBC) catastrophic loss data.** The Insurance Bureau of Canada (2020) publishes weather-related catastrophic loss data dating back to 1983.[5] From 1983 to 2019, Canada experienced 271 weather-related catastrophic loss events, with a total cost of $31.8 billion ($2019). Major catastrophic losses are tracked for a range of weather-related disasters including wildfires, windstorms, floods, winter storms, hurricanes, and hail.

Both datasets point to alarming trends (see Figure 2).

Canadians are experiencing a growing number of disasters each year—but the total cost of disasters is growing faster.

Both data sets indicate that events are becoming more frequent, while total costs and average costs are climbing:

The annual number of disasters in the CDD has steadily increased since the 1970s, fluctuating between a low of eight in the early 1970s to a high of 27 per year in 2016. The number of events

[3]All costs in this section are expressed in 2019 Canadian dollars, normalized by using nominal Gross Domestic Product (or GDP at market prices). Nominal GDP is a good price inflator to use to normalize disasters costs in constant dollars since it captures increases in the accumulation of assets and population and not just price inflation as with the consumer price index.
[4]Heat events were omitted due to a lack of data.
[5]Sources cited by IBC for the data include: IBC, PCS Canada, Swiss Re, and Deloitte (1983 to 2007); CatIQ (2008 to 2020).

is also trending up. This increase, however, is small compared to how the costs of disasters have ballooned—rising from an average of $8.3 million per event in the 1970s to an average $112 million in the 2010s. This change represents a staggering 1,250 per cent increase over just four and a half decades. There have been $14.5 billion in disaster costs tallied so far for 2010 to 2019, while the total for the four previous decades was $21 billion. The $21 billion includes the 1998 Eastern Canada ice storm—a $7 billion event.

Weather-related insured catastrophic loss events for the three decades prior to 2010 averaged five per year, with total catastrophic losses of $12.7 billion. But between 2010 and 2019, the annual average number of events jumped to 11, resulting in a total cost of $20.1 billion, or nearly double the costs of of the previous three decades combined. In 2018 and 2019 alone, reported insured catastrophic losses totalled $3.1 billion from 23 weather events—or about one every month. These costs are also getting larger, with the average cost per event quadrupling from an average of $44 million in the early 1980s to $175 million from 2010 to 2019.

Weather-related disaster costs are high.

Disasters are becoming costly for individuals and for the economy. On a per capita basis, costs in both datasets rose from about $6 per person prior to 2010 to $40–$50 per person after 2010, or a nine-fold increase in the average before 2010.

Of course, this average value masks very acute costs for individuals who are directly affected by the disasters. For example, the 630,000 people[6] evacuated due to weather-related disasters since 1970 would have experienced costs well above this national average due to lost income, relocation costs, and uninsured property losses.

Compared against the growth in Canada's gross domestic product (GDP), which has grown at an annual rate of about 2.6 per cent per year since 1970,[7] weather-related disaster costs have been increasing. Prior to 2010, disaster costs in both datasets were equal to about 0.028 per cent of the annual 2.6 per cent GDP growth.[8] After 2010, this share rose to five to six per cent of annual growth in both datasets. In 2016, an extreme weather year and slow GDP growth year, disaster costs equaled a third of all of Canada's GDP growth.

The Fort McMurray wildfire of 2016, the largest single weather-related insurance loss event in Canadian history, resulted in nearly $4 billion in insured losses (IBCb, 2020b). The combined property, infrastructure, business interruption, and other indirect economic losses of the Fort McMurray wildfire have been estimated at almost $11 billion (Alam, et al. 2017), equivalent to 3.5 per cent of Alberta's GDP—or about 1.5 years of lost provincial economic growth.

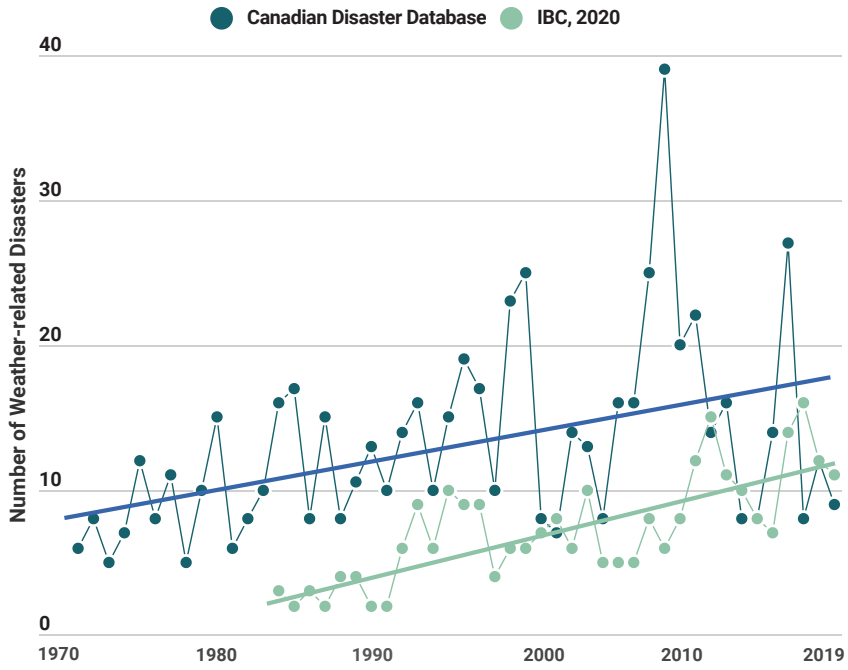
[6]Reported in the CDD.
[7]Statistics Canada. Table 36-10-0369-01 Gross domestic product, expenditure-based, at 2012 constant prices, annual (x 1,000,000).
[8]Or one per cent of annual growth.

FIGURE 2

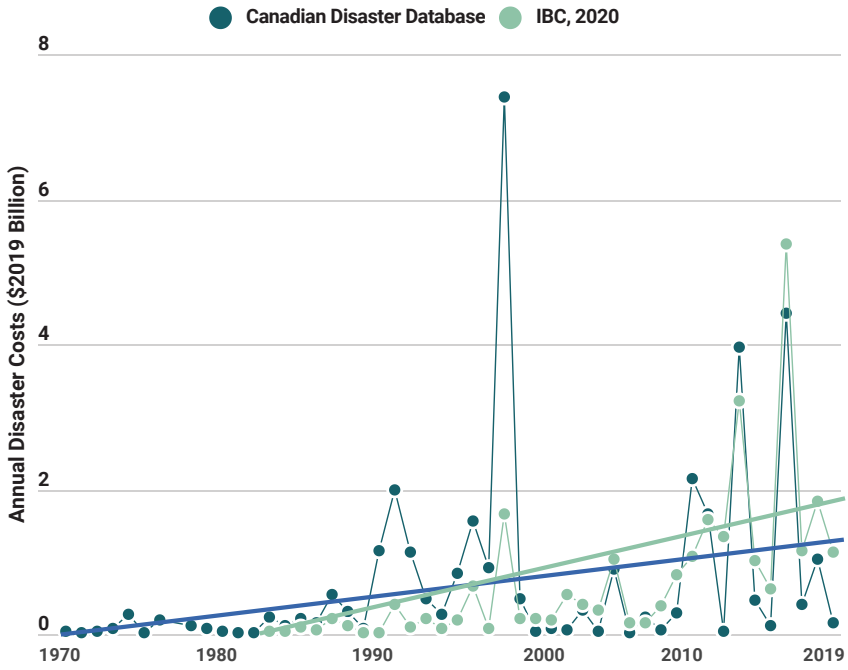
THE **RISING COSTS** OF WEATHER-RELATED DISASTERS

The Canadian Disaster Database (CDD) records the costs of declared disasters in Canada, and the Insurance Bureau of Canada (IBC) records catastrophic insured losses. Both sources show eye-opening trends in weather-related disasters and events.

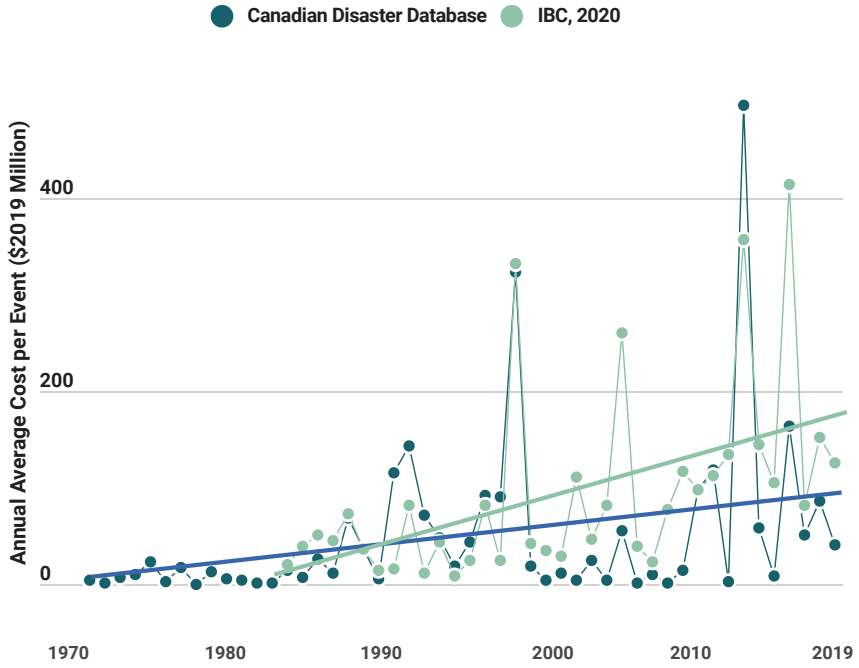
Weather-related disasters are hitting more often



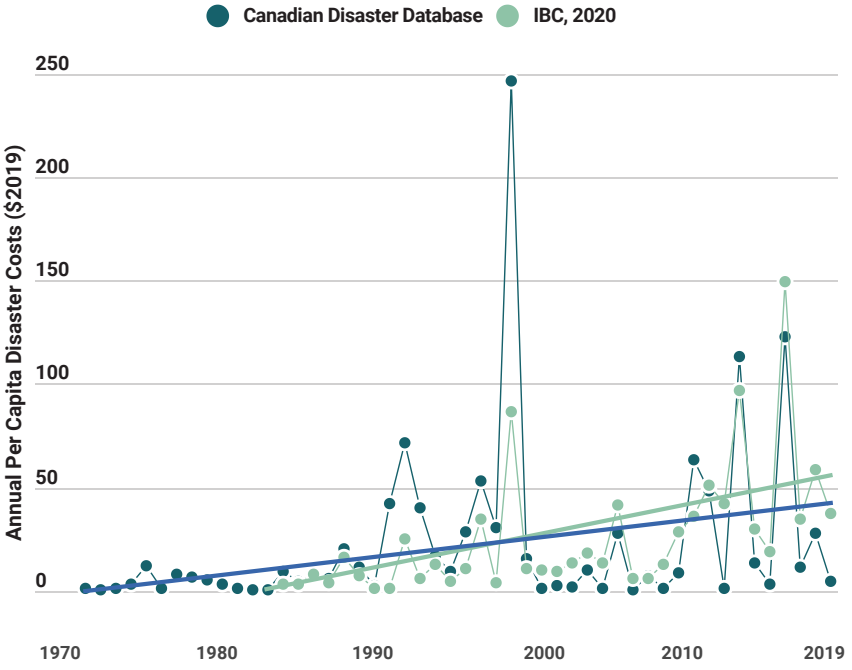
Weather-related disasters are costing more each year



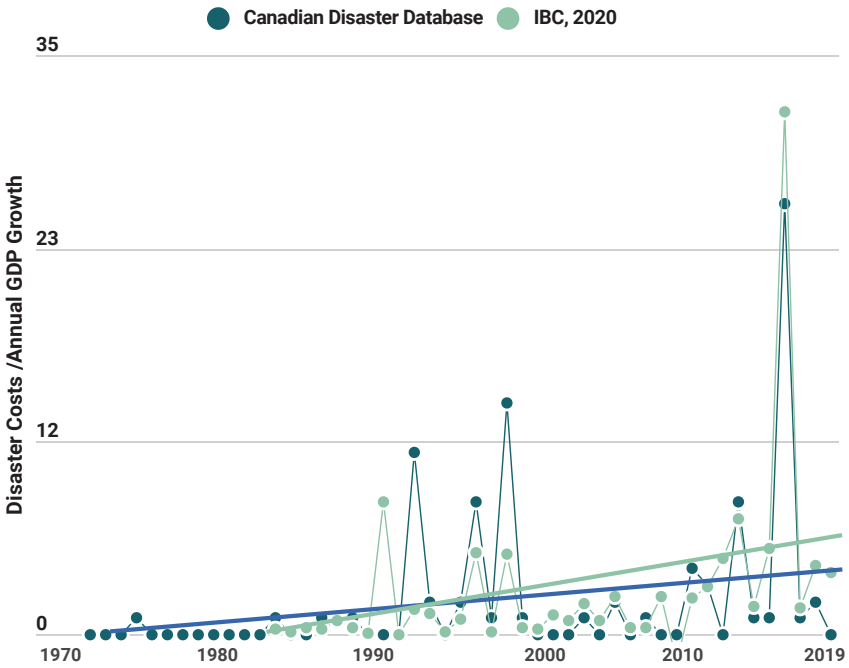
Weather-related disasters are getting more expensive on average



Per capita disaster costs are rising



Disasters are costing more as a share of GDP



Not all disaster costs are linked to climate change

While the data leaves no question that climate change is increasing the risks and costs of weather-related disasters in Canada, not all increases in disaster risks and costs should be attributed to a changing climate. Further analysis of the possible causes of specific events is required.

Climate change is intensifying weather-related disasters.

Credibly evaluating the costs of climate change, and particularly the past costs of extreme events, requires assessing the extent to which disasters would happen in the absence of climate changes driven by human activity. There is a growing body of science that can help establish the influence of climate change relative to more conventional factors on extreme weather events. Known as extreme event attribution, this field of study has generated mounting evidence that greenhouse gases from human activity are raising the risk of some types of extreme weather. A recent survey of over 300 peer-reviewed attribution studies found that, since 2011, human-caused climate change had made 280 global extreme weather events and trends more likely or more severe (Carbon Brief, 2020).

Extreme event attribution has fingerprinted climate change in recent Canadian disasters.

The 2013 Alberta floods, which caused $1.8 billion in catastrophic insurance losses and $6 billion in direct costs such as uninsured losses (CESD 2016), were the combined result of above-average snowmelt that year and extreme rainfall made more likely because of the changing climate (Teufel et al., 2016).

The Fort McMurray wildfire of 2016 has similar links to climate change. The fire resulted in $4 billion of insured losses, destroyed 2,400 buildings, and led to over 80,000 people being evacuated. The United States' National Oceanic and Atmospheric Administration (2016) and Canadian researchers (Kirchmeier-Young et al. 2017) determined that this "gargantuan fire" was driven by several fire-friendly atmospheric and ground conditions that had been made signifi-

The Fort McMurray wildfire of 2016 resulted in $4 billion of insured losses, destroyed 2,400 buildings, and led to 80,000 people being evacuated.

cantly more likely because of climate change. These include: drier-than-average conditions in 2015 that left dry timber as fuel for the inferno; below-average amounts of precipitation manifested as an early snow melt, extending the fire season; and dry air along with well-above-average spring temperatures that dried out vegetation prematurely, providing additional fuel.

Climate change aside, Canada's expanding economy, population, and other compounding factors are increasing our vulnerability to weather-related disasters.

As we explored above in this section, disaster costs are growing. Contributing factors include an expanding economy, rising property values, and increased residential and commercial development pushing into hazardous areas. But that is not the whole story; growing and compounding vulnerabilities are also driving the uptick in catastrophic losses. Flood costs, for example, are also compounded by the loss of natural habitats that protect against flood, aging municipal infrastructure ill-suited to the range of extreme events now being experienced, buildings that don't incorporate sufficient resilience measures, and the expansion of impermeable surfaces that create more runoff in urban areas (Intact Centre, 2020). Further, poverty, discrimination, and marginalization have left many, including Indigenous people, more severely impacted by disasters and with fewer resources to prepare, respond, and recover (Adger, 2014; Birkmann, 2015).

Focusing on weather-related catastrophic losses and disaster spending only paints a partial picture of climate change costs. Other types of climate change damages are more gradual and less dramatic than changes in extreme events. Studies in the U.S. and Europe have shown the costs of slow-onset climate change impacts—such as declining fisheries caused by ocean acidification, lost hydroelectric generation capacity due to changing rainfall patterns, sea-level rise that permanently floods low-lying areas and erodes coastlines, and collapsing buildings and roads caused by permafrost thaw—may be of similar magnitude to those associated with weather-related disasters and climate extremes (Ciscar et al., 2018; Martinich and Crimmins, 2019; Steininger et al., 2016).

The next chapter of the report explores this broader range of climate change costs.

PERMAFROST THAW ACROSS NORTHERN CANADA

Permafrost thaw is one of many climate change impacts affecting communities across Northern Canada. Much of the North has been covered in permafrost for millennia as ground temperatures in these areas have largely remained well below freezing. However, warmer temperatures caused by climate change are causing permafrost to thaw, resulting in shifting, slumping, and cracking of the ground. This leads to damage and destruction of homes, schools, health centres, highways, and runways built on permafrost (Couture et al., 2003; Government of Northwest Territories, 2014; Hjort et al., 2018; Pan-Territorial Adaptation Partnership, 2014). Shoring up, rebuilding, and dealing with the disruption caused by failed infrastructure has become a perpetual expense for individuals, communities, businesses, and governments (CCA, 2019; Senate of Canada, 2019).

In addition, permafrost thaw may become a major threat to health, well-being and ways of life in Northern Indigenous communities (CCA, 2019; Senate of Canada, 2019). On top of ongoing impacts to traditional harvesting practices, unaffordable prices of store-bought food, high rates of mental illness and suicide, and long-term boil water advisories, permafrost thaw impacts to Northern homes, buildings, and infrastructure will further reduce the options Indigenous communities have for food, water, shelter, and healthcare (CCA, 2019; Senate of Canada, 2019).

Permafrost thaw has been increasingly eating into the budgets of Northern governments over the past decade. The Northwest Territories Association of Communities estimates that permafrost thaw results in $51 million in damages to public infrastructure every year—or 18.5 per cent of the territory's total infrastructure budget for 2020 (EnviroEconomics and Tetra Tech, 2018; Government of Northwest Territories, 2020). Similarly, the Government of Yukon has spent an additional $400,000 each year on road maintenance on the Dempster Highway due to permafrost thaw; over the past 13 years permafrost-related maintenance costs for the one highway alone have increased by an estimated $2 million, making up an estimated three per cent of the territorial government's transportation operations and maintenance costs (Burn, 2018; Government of Yukon, 2020).

The impacts of permafrost thaw on Northern airports is of particular concern. Across the North there are 117 airports that serve as the only means of year-round access to communities (Office of the Auditor General, 2017). As with many infrastructure systems across the North, many of these airports are already in disrepair and can ill afford more damage (Government of Nunavut, 2014). Recent analysis has estimated that the impact of thawing permafrost to airports in the Northwest Territories is 23 per cent of the total asset value (EnviroEconomics and Tetra

Tech, 2018; Northwest Territories Association of Communities, 2015). Indirect costs of these airport impacts are estimated to be $8.03 million per year in business disruptions and $5.76 million per year in labour income loss (ibid).

The Inuvik airport is a salient example of the economic impact of permafrost thaw and of the opportunity to reduce those impacts into the future through adaptation. Serving over 7,000 people in the Beaufort Delta Region, the airport has been impacted by permafrost thaw over the past decade, with service disruptions and mounting costs. A recent investment of $22 million for improved drainage and widening to slow the pace of permafrost thaw beneath the runway is anticipated to extend the life of the airport and reduce service disruption and costs associated with critical failures. Other adaptation options are increasingly being integrated into capital planning across the North (Allard et al., 2012), such as thermosyphons that protect the integrity of existing permafrost under buildings and infrastructure. These adaptation measures can reduce the costs of long-term damage by up to 45 per cent (Larsen et al., 2008; Melvin et al., 2017). However, given that surface permafrost thaw is inevitable in many parts of the North, consideration also needs to be given to land-use planning and regular lifecycle analysis, as well as the reality that, in some cases, replacement of vulnerable infrastructure may be more cost-effective in the long term than trying to protect it in place.

The adaptation response thus far has been ad hoc and underfunded, despite the dramatic and clearly visible climate impacts that represent a major threat to Northern economies and ways of life (Labbé, 2017; Loboda, 2014). Efforts to patch over damage can amount to throwing good money after bad. Innovative solutions involving new building and infrastructure construction technologies may hold promise, but remote and Indigenous communities often cannot bear the costs to implement them. Indigenous people facing large impacts in the North must be included as rightsholders in the conversations around what is taking place, given the thousands of years they have been living on these lands and the impacts that these communities face.

A deeper understanding of the large-scale and long-term implications of permafrost thaw to communities and economies across the North, as well as the benefits and limitations of permafrost adaptations, is required to inform a concerted strategy. The Institute is contributing to this understanding through forthcoming research in this series. That research will evaluate the future risk of permafrost thaw across the North and estimate the potential impacts and costs to the roads, buildings, and airports. It will also assess the degree to which adaptation measures can reduce these costs in the medium and long term, including the balance of costs between measures that slow the rate of thaw and complete infrastructure redesign and replacement.

CLIMATE COSTS ARE FAR-REACHING AND PILING UP

Insured losses and other disaster-related costs represent just a fraction of the total economic costs of extreme weather events. Other costs—including business interruption, long-term physical and mental health effects, and depletion of government resources—profoundly add to the price tag. Further, the impacts of climate change will not be limited to those associated with larger and more frequent extreme weather disasters. Slow-onset changes will have impacts and costs of a similar magnitude to extreme weather events.

This section provides a view of the range of costs attributable to extreme events and to slow-onset changes across social, economic, and environmental systems in Canada. Based on our review, the Institute identified five types of climate-related damages that are happening now and likely to continue:

- **Household, business, and infrastructure assets are losing value.**
- **Productivity losses and business disruptions are slowing economic growth.**
- **Human health is at risk.**
- **Impacts on ecosystems generate tangible costs.**
- **More government resources will be required to address climate change damages.**

The information below is organized under these five types of damages, presenting a mix of historical and projected cost information intended to signal the scope and scale of Canada's climate change costs.

Limitations in existing analysis make a truly comprehensive assessment challenging, however. Based on existing information, the costs of climate change for Canada are likely to be large and pervasive. And that's before accounting for all the unknowns that make up the rest of the iceberg.

Household, business, and infrastructure assets are losing value

The value of household, business, and infrastructure assets at risk are considerable. For example, real estate represents more than 75 per cent of Canada's produced wealth, with a value of over $8.5 trillion. Canada's transportation and electric power infrastructure alone have a replacement value of over $400 billion, and the reliability of this infrastructure is vital to the economy and to the everyday lives of Canadians.

Homes, buildings, and infrastructure are extremely sensitive to several climate hazards that are expected to become more frequent and intense because of climate change. Until very recently—and in many cases, continuing today—urban development, public infrastructure such as roads and power lines, and industrial facilities were not designed to withstand future climate change, adding to their vulnerability. The climate change hazards placing infrastructure at risk include flooding from heavy rainfall and storm surges, more frequent wildfires, and thawing permafrost—all of which will be exacerbated by steady warming.

- **In the absence of adaptation, coastal property losses could equal half a year's GDP growth by mid-century.** Withey et al. (2015) assess the national costs to dwellings and agricultural and forest lands from sea-level rise and storm surges under various future climate scenarios. Between now and mid-century, they estimate cumulative property damages nationally could range between 0.39 and 0.80 per cent of current GDP. For some regions, the cumulative impact to mid-century exceeds one per cent

of their current GDP: notably New Brunswick, Quebec, the territories, and British Columbia.

- **Permafrost thaw will degrade community infrastructure.** In the North, accelerated permafrost thaw will continue to undermine building foundations and municipal infrastructure, forcing early replacement, higher maintenance costs, and impaired function. Permafrost thaw in the Northwest Territories' 33 communities is estimated to rack up $1.3 billion in costs over the next 75 years, equal to about 25 per cent of current territorial GDP (EnviroEconomics and Tetra Tech, 2018). Because housing and infrastructure are very expensive to build and maintain in remote Northern Indigenous communities, these impacts will exacerbate the inequities Indigenous peoples are already experiencing as a result of low individual incomes, restricted community budgets, and a lack of government investment.

Productivity losses and business disruptions are slowing growth

- **Wildfires shuttered oil production, reducing economic value.** The Fort McMurray fire reduced oil production by approximately 47 million barrels with a market value of $1.4 billion (Antunes, 2016). It is unclear if this production was delayed or lost entirely due to supply constraints to get oil to market, but it likely led to economic losses given the size of the shutdown. At the peak of the fire, about 40 per cent of Canada's total oil production was taken offline, resulting in lost profit, royalties to government, and wages.
- **Alberta floods left many without work temporarily, lowering overall productivity.** The 2013 Southern Alberta floods left 300,000 individuals, or 14 per cent of Alberta's workforce, unable to work over a two-week period. This equalled 5.1 million hours of lost work due to the flooding and resulted in $601 million of lost economic output that is equivalent to 0.2 per cent of provincial GDP (Government of Alberta, 2015).
- **Recent spring floods impacted small and financially vulnerable businesses.** For weeks, the spring floods of 2019 in New Brunswick, Quebec, and Ontario inundated areas where 3,800 businesses were located. The vast majority were small businesses in the retail and construction industries with fewer than five employees (Statistics Canada, 2019). Financial data indicates that small business is much more vulnerable to business disruptions than the rest of the economy, with operating profit levels well below the average for all business.[9]

Of course, acute disasters receive the attention. But the slow-onset changes also impact productivity. Recent analysis by Kabore and Rivers (2020) used Statistics Canada survey data from industry to estimate a link between manufacturing output and temperature. They conclude that when the temperature exceeds certain thresholds, defined as below -18° C or above 24° C, has historically dropped annual manufacturing output by 2.7 per cent on average, with extreme hot and cold temperatures contributing about equally to this impact. Given that manufacturing accounts for 10 per cent of Canada's GDP, even small drops in manufacturing output equate to large productivity losses.

[9] In 2018-19, retail trade had profits that were one third the level of all industries in Canada, while the level for construction was about half (Statistics Canada Table 33-10-0008-01). Small businesses tend to underperform larger enterprises across a range of financial performance indicators (Government of Canada: Financial Performance Data. Accessed June 25, 2020, from https://www.ic.gc.ca/app/sme-pme/bnchmrkngtl/rprt-flw.pub?execution=e1s1).

People's health is at risk

Disasters, extreme weather events, and slow-onset climate changes have been linked to increased deaths and illness, which increase stresses and costs on the health care system and reduced quality of life (Heath Canada, 2016). The range of health vulnerabilities and costs is broad:

- **Extreme events make mental health worse.** In the Northwest Territories, the 2012 and 2013 wildfires exacerbated feelings of loneliness, fear, stress, and uncertainty, including among Indigenous peoples (Dodd, et al., 2018). Symptoms of mental illness were also elevated after the Fort McMurray 2016 wildfire and included depression, moderately severe depression, suicidal thinking, and substance use (Brown, et al., 2019).
- **Wildfire smoke harms people.** Health Canada estimates that between 620 and 2,700 deaths per year can be attributed to fine particle emissions from wildfires between 2013 and 2018, excluding the Fort McMurray wildfire of 2016 (Matz et al., 2020).
- **Extreme heat causes children to miss school.** Only 128 of the 583 schools in the Toronto District School Board have air conditioning, which exposes students and workers to significant heat stress and has led to parents keeping children home from school (Flanagan, 2018).
- **Extreme heat is deadly.** In Ontario, each 5° C increase in daily temperature has been shown to result in a 2.5 per cent increase in non-accidental deaths (Chen et al. 2016). The Quebec heat wave in summer 2018—the hottest summer in 146 years of record-keeping—caused 86 deaths; 291 deaths were recorded during the 2010 heat wave (ClimateData, 2020). Families with less money are disproportionately impacted by these tragedies as they are often unable to afford air conditioning.

Ecosystem impacts generate tangible and intangible costs

Ecosystem costs can manifest as losses in market value—for instance, when crop yields change—but also in less tangible ways, such as cultural loss or changes in recreational experiences and opportunities. Examples include:

- **Fisheries will be disrupted.** Warming and acidification of Canada's oceans and warming of inland waters may decrease the overall productivity of fisheries and impact the food security and cultural practices of Indigenous communities (Campbell et al., 2014; Weatherdon et al., 2016). A reduction in the overall size of fisheries can create tensions between Indigenous and non-Indigenous communities as they compete for a diminishing resource. These tensions have, at times turned violent.
- **Harmful algae blooms wreck beach days and hurt tourism.** Harmful algae blooms in Lake Erie, if left unchecked on their current trajectory as the climate warms, could reduce recreational values by $155 million annually to mid-century, impairing the enjoyment of recreational fishers, boaters, and swimmers. Impacts on the tourism industry are estimated to be in the order of $110 million annually to 2040 (Smith et al., 2019).
- **Early heat waves compounded with frost to kill apple blooms.** A March 2012 heat wave in Ontario caused fruit trees to blossom weeks earlier than usual making them vulnerable to the April frosts, which ultimately killed 80 per cent of the apple blossoms. The resulting lost harvest value was estimated at $100 million (Government of Canada, 2015).
- **Wildfire prevention is increasing land management costs.** The direct costs to the forest sector for wildland fire protection has increased by approximately $120 million per decade since the 1970s and routinely costs more than $1 billion annually (NRCan, 2017 and 2019). Some of these costs are for adaptive responses, such as controlled burns, to avoid future damages.
- **More pests ruin harvestable wood.** The mountain pine beetle outbreaks in British Columbia between 2003 and 2005, which have been linked to a warming climate, decreased harvestable pine by over 50 per cent, with a present value cost of $60 billion in lost production (Corbett et al., 2016).

More government resources will be required

Canadian governments of all levels are spending more to adapt to climate change and respond to the disasters and healthcare stresses that climate change creates. Those expenditures have opportunity costs: funds could otherwise be used to deliver other benefits or priorities. Typical costs experienced include:

- **Increased capital expenditures** linked to accelerated asset depreciation and upkeep for transportation infrastructure, public buildings, land easements, underground infrastructure, and water treatment facilities.
- **Increased operation and maintenance costs,** as demand for healthcare services rise, disaster response becomes more frequent, government self-insured liabilities and insurance premiums rise, and potential transfer payments rise between levels of government to backstop liabilities.

Specific examples of increased government spending due in part to climate change-related impacts include the following:

- **More disaster spending is needed to cope.** In 2016, the Parliamentary Budget Office concluded federal spending for disaster recovery in the provinces and territories was on the rise and would continue to climb well above historical levels. Canada's Disaster Financial Assistance Arrangements program is projected to cost on average $673 million annually for floods and $902 million for weather-related disasters in the next few years. This is well above the hundred million-dollar annual spending forecast for the DFAA (PBO, 2016).

- **Fire management costs for government are rising.** By the end of the century, total average national fire management costs are projected to increase to just under $1 billion a year (a 60 per cent real increase from the 1980–2009 period) under the low greenhouse gas emissions pathway and $1.4 billion a year (a 119 per cent real increase from the base period) under the high emissions pathway (Hope et al., 2016).
- **Damage to community infrastructure is on the rise.** As one example, the National Capital Commission estimated that repairing infrastructure damage from the spring floods of 2019 would cost $6 million to $10 million representing 20 per cent of its forecast annual expenditures for operations. This cost is on top of $2 million in repairs required after the 2017 floods (Porter, 2019).

In the next section we discuss the role that climate change adaptation can play in reducing these costs.

THE NEED TO ADAPT AND BUILD RESILIENCE TO CLIMATE CHANGE

The future impacts and costs of climate change for Canada are not inevitable—nor are they entirely outside our collective control. How Canada responds will ultimately affect the costs of climate change across the country.

In the long term, overall global reductions in greenhouse gas emissions are critical to limiting the climate disruption that Canada will experience. However, existing greenhouse gas emissions have locked in a significant degree of climate change that can no longer be prevented. Reducing emissions today and in the future will help prevent the worst of the damage, but even in the best-case scenario for emissions, Canada will still be faced with a changing and unstable climate for many decades or centuries to come.

Preparing for the growing climate risks that have been set in motion can reduce impacts and costs. Adapting and building the resilience of communities, businesses, and individuals can reduce the severity of climate change impacts occurring today and the potential impacts yet to come (Araos, 2016; Lesnikowski, 2015 and 2016). These can also ensure a faster recovery from impacts that cannot be avoided.

While the awareness of the need for climate change adaptation in Canada is growing and more and more individuals and organizations are considering new risks in their day-to-day choices, action so far remains insufficient to substantially reduce Canada's vulnerabilities. While there are many promising examples of adaptation being implemented, progress is inconsistent across different regions, communities, economic sectors, and governments. In the meantime, economic, social, and environmental costs continue to spiral.

The path forward may be shrouded in fog, but standing still is not an option. Experts and deci-

Preparing for the growing climate risks that have been set in motion can reduce impacts and costs.

sion makers don't fully understand the impacts that climate change may bring, let alone which adaptation solutions will best reduce these impacts. However, the Institute's work on the costs of climate change adds to past findings by governments and researchers across the country to illustrate that climate change impacts and costs will be massive—so big that governments, industry, and communities need to rapidly harness all available tools and knowledge to move forward with adaptation.

Adaptation takes many forms

Climate change adaptation means actions that reduce the negative impacts of climate change and protect individuals, communities, and economies. Those actions can also take advantage of opportunities that disruptions bring to improve the way things are done, increase prosperity, and better quality of life (IPCC, 2014; Smithers & Smit, 1997). Some kinds of adaptation are already occurring and will continue to occur as individuals, government, businesses, and ecosystems experience climate changes and are forced to respond. However, climate change is so pervasive a challenge that these kinds of spontaneous responses alone cannot be relied on to protect the well-being and prosperity of Canadians. Climate change adaptation also requires deliberate, proactive choices by individuals, families, communities, businesses, and governments to incorporate the risks and opportunities of a changing climate—and an unpredictable future—as a way of living and doing business.

Adaptation can take many forms. Upgrades to physical infrastructure such as roads and storm sewers can ensure it functions in, and protects Canadians from, a harsher climate. New practices can help prepare for a new climate reality; for example, agricultural operations can be made more resilient to heat and drought, and schedules can be changed for outside workers who are experiencing more frequent heat waves. Government policy can support risk reduction, for example by changing land use planning to avoid development in growing flood risk zones or by updating building standards to reflect the future climate that buildings and infrastructure will need to withstand. And the

capacity of governments and communities to respond to climate change and weather-related disasters can be improved through investments in early warning and emergency response.

Adaptation is also critical to building capacity and preventing further disproportionate impacts to communities that have been made vulnerable by disenfranchising policies, such as among low-income and non-white communities (Ford, et al., 2015; Kates et al., 2012). The inherent resilience that many marginalized communities derive from social cohesion can be strengthened and consolidated through investment in local networks and the capacity of community groups.

Specific investments to reduce poverty and ensure equitable access to housing, health care, education, and economic opportunity can also reduce vulnerability and increase resilience. These investments can limit the consequences of both climate change and other kinds of shocks, reducing governments' and communities' long-term costs related to emergency response and social assistance (Cutter, 1996; Ribot, 2014; Adger et al., 2014).

Because the Government of Canada has committed to achieving reconciliation with Indigenous peoples through a renewed nation-to-nation, government-to-government, and Inuit–Crown relationship, adaptation in Canada will also require more reflection on the rights of Indigenous peoples to the conservation and protection of the environment and the productive capacity of their lands, territories, and resources (Article 29, United Nations Declaration on the Rights of Indigenous Peoples). Doing so enables Indigenous peoples to determine adaptation priorities and develop strategies that best fit the needs of their communities (Article 32, United Nations Declaration on the Rights of Indigenous Peoples).

The benefits of adaptation go beyond avoiding costs

Just as the costs of climate impacts take many forms, so too do the benefits of adaptation. These benefits need to be understood to make informed decisions about adaptation.

The most obvious benefit of climate change adaptation is that it can help avoid the damages and costs of future impacts. In many cases, adaptation can reduce damages and costs immediately—even before dramatic climate changes take place—because communities, homes, businesses, and infrastructure are already at risk in the current climate. From this perspective, good adaptation is not just about protecting ourselves against future climate disruption. It is also a chance to reflect more broadly on how climate and weather affect the lives of Canadians, and to plan for inevitable variability.

Analysis consistently demonstrates that every dollar spent on appropriate adaptation can return many dollars in the form of avoided costs of damages and of social and economic disruption (GCA, 2019). Measures to protect homes and communities from wildfires (Abt et al., 2015), coastal flood and erosion protection (Boyer-Villemaire et al., 2016), flood warning systems (Pappenberger et al., 2015), and relocating neighbourhoods in areas (Godschalk, 2009; Förster and Muelenaere, 2011) are all examples of adaptation actions for some of Canada's greatest climate risks that have been shown to generate significantly greater economic benefits than the costs invested.

However, the benefits of adaptation can extend well beyond avoided costs of climate and weather

impacts—especially if they deal with the causes and not just the symptoms of climate risk. Often, weather and climate-related disruption occurs because many aspects of society—cities, economies, industries, and social programs—are designed to work efficiently but under a narrow range of conditions. When change, shocks, and stresses take those operating conditions outside of the acceptable range, catastrophe can result. Climate change is now altering the operating range for Canadian society in ways that are not entirely predictable, meaning that systems must be designed in ways that increase their resilience to a range of conditions. Doing so not only reduces climate change risks; people also benefit from a society that is more stable, functional, and prosperous in the face of many types of change. If we collectively play our cards right, this creates the potential for multiple social, environmental, and economic benefits.

For example, the runoff from rainstorms in Canadian cities is typically carried away by complex systems of sewer pipes and drainage channels. The increasing intensity of rainstorms from climate change threatens to exceed the capacity of these pipes and channels and cause flooding of properties and basements more often. However, even under normal conditions, cities are beset by flooding and water quality problems because these drainage systems do little to reduce the speed, quantity, and quality of dirty runoff from urban asphalt and concrete surfaces.

Adaptation that combines improvements in conventional storm drainage infrastructure with natural infrastructure such as green roofs, stormwater wetlands and urban tree planting can reduce and treat runoff and help control flooding and water pollution—both immediately and as climate change exacerbates the problem. But the benefits extend further by building resilience to more frequent extreme heat by cooling homes and neighbourhoods and reducing building energy use, making urban environments more attractive, and increasing property values (O'Neill, 2015).

Canada's adaptation deficit is growing

Despite clear evidence of growing climate change risk across Canada and the potential for immediate and sustained cost savings and benefits, adaptation in Canada has not been keeping pace (Ford et al., 2015; Paterson et al., 2012). Much of Canada's existing physical infrastructure—both public and private—is at risk

from current and future climate change, but there are few plans in place to address these risks. Most new investments in infrastructure, real estate development, and industrial expansion don't account for the risks of a changing climate (CCA, 2019; NRTEE, 2011), although Infrastructure Canada's Climate Lens assessment framework now seeks to change this for some projects (Infrastructure Canada, 2020).

Health risks from climate-change-induced heat, air pollution, and infectious diseases are also increasingly clear, but health adaptation across Canada is slow to get started and regionally inconsistent (Austin et al., 2015). Northern regions and communities are being more dramatically affected by climate change impacts than the rest of Canada and frequently lack the resources to respond to the scale of change they are experiencing (Ford et al., 2015; Healey, 2015; ITK, 2016). Legacy policies that have perpetuated housing shortages, health-care delivery, and infrastructure disrepair, as well as persistent food and water insecurity in Indigenous communities—all of which increase climate vulnerability—are still not being addressed (Expert Panel on Climate Change Adaptation and Resilience, 2018; ITK, 2016; Parlee & Furgal, 2012).

Why are we collectively not acting faster? The most obvious reason is that governments, communities, businesses, and individuals don't have a deep enough understanding of the risks and costs of climate change to inform action. Canada's Auditors General have highlighted that the Government of Canada and provincial governments are lagging significantly in the characterization of climate risks necessary to support adaptation (OAG, 2018). Leaders of Canada's financial sector have warned that the absence of consistent and reliable information about the physical risks and costs of climate change is limiting their ability to price those risks (Smart Prosperity, 2020). Without useful information about risk and costs and processes to incorporate that information into decision making, there is no clear mechanism to steer governments, businesses, and individuals away from climate change risk and towards resilience and adaptation solutions.

In some areas, however, there is a deep understanding of how climate change will impact Canada, including costs, and individuals and organizations are still not acting. For example, for more than a decade Canada's insurance industry has been highlighting the impacts and costs of climate-driven extreme events such as flooding and wildfires. They have demonstrated (as we have echoed above) that these events are growing bigger, more frequent, and much more costly (IBC, 2018). However, Canada has been slow to implement adaptation measures that could reduce known risks and costs, even those that are relatively inexpensive and highly effective. Like many other nations, Canada is struggling to act on known climate change risks and implement adaptation at scale. This shows that understanding risks and costs is only a starting point; much more work is required to set up the policies, governance, expertise, and financial mechanisms to execute adaptation.

Addressing Canada's adaptation deficit is a difficult process that will not happen overnight, but there is no time to lose. On one hand, Canada needs to move forward in a context of often incomplete information (Moser, 2010; Haasnoot, 2012). On the other, adaptation must be a higher priority for leaders, decision makers, and Canadians everywhere so that it can get the focus, resources, and coordination that it needs.

CASE **STUDY**

CANADA'S FLOOD RISK

Floods have historically been Canada's most destructive and costly natural disasters, representing 37 per cent of all disaster costs since 1970 in the Canadian Disaster Database, for example (see Figure 2). Canada is susceptible to many forms of flooding. Coastal flooding along maritime coasts and the shores of inland lakes results from high water levels created by combinations of high tides, strong winds and storm surges. Riverine flooding occurs when river and stream flows overtop their banks because of high rainfall, rapid snowmelt, ice jams, or a mix of these. Pluvial flooding takes place primarily in urban areas, where intense rainfall overwhelms the capacity of storm drains and causes backups and overflows into homes and basements. Across all flood categories, about 10 per cent—about 1.8 million— of homes in Canada are estimated to be at a high risk of flooding (Canadian Underwriter, 2016). Continued urban development and intensification in flood hazard zones across much of Canada has also contributed significantly to increased impacts and costs over time (Trudeau, 2017).

The total costs of floods can be enormous. The 2013 riverine flooding in Calgary and Southern Alberta is estimated to have cost governments, businesses, homeowners, and insurers over $5 billion (MNP, 2015). Pluvial flooding localized in some areas in Toronto that same year cost nearly $1 billion—still Ontario's most costly insured weather event of all time (IBC, 2017b; IBC, 2018). In an average year, Canadian private insurers pay out between tens of millions and hundreds of millions of dollars for flood claims, with extreme flood years such as 2013 resulting in over $3 billion in payouts. Governments pick up many of the remaining costs; the federal government Disaster Financial Assistance Arrangements program currently needs about $700 million annually for flood response and recovery, much of which is also matched by provincial governments (PBO, 2018). There are other significant public costs as well, such as tens of millions of dollars annually for evacuations of First Nations communities that have been relocated, often against their will, in areas prone to regular flooding (CBC, 2016).

In Canada, climate change is expected to affect the frequency and magnitude of all types of flooding. Rising sea levels and surges from more intense storms will dramatically increase the number of homes, properties, and businesses at risk of coastal flooding in Canada, particularly in B.C.'s Lower Mainland (Fraser Basin Council, 2016). More frequent intense rainfall, expected across much of the country, will almost certainly increase the number of pluvial flood events. It may also increase the risk of riverine flooding, although it is still unclear whether the overall risk will increase because riverine floods are caused by a number of factors that will be affected differently by climate change (e.g.,Teufel et al., 2017).

On the climate costs iceberg, flooding is one impact that's clearly visible above the waterline. We know that Canada is already at risk of flooding, and that climate change is likely to make it worse. However, even for this most visible of potential climate change impacts, the path forward is not entirely clear. To begin, experts don't even understand entirely which areas of the country are at existing risk of flooding nor the total value of property at risk, as Canada's flood maps are incomplete, dated, and inconsistent (Henstra et al., 2019). Without this baseline of understanding, it is not only difficult to project how flood risk and cost will evolve under climate change but also to prioritize specific areas for adaptation investment and to select the adaptation measures that will be most appropriate.

In some cases, simple and inexpensive adaptation measures can be installed by homeowners to prevent flood impacts (Intact Centre, 2019). In others, millions of dollars in engineered infrastructure such as dams, reservoirs, and underground drainage systems may be required to mitigate both current and future flood risk. The most cost-effective adaptation measure in some situations may even be to relocate homes or entire neighbourhoods from high-risk areas. But without knowing either the overall scale of current and future flood risk in Canada, or the details of what is at risk in particular locations, it is challenging to mount a concerted adaptation response.

Our research on the costs of climate change will bring clarity to existing and potential future flood risk in Canada by characterizing the overall scale of impacts and their associated costs. In the absence of national flood mapping, we use risk maps developed for the insurance industry to determine where coastal, fluvial, and pluvial floods threaten property and assets across the country and apply climate projections to estimate how impacts and costs might grow under climate change. We also examine the potential for adaptation interventions to contain or reduce those growing costs.

RECOMMENDATIONS

The costs of climate change are massive and mounting. Despite gaps in knowledge, climate change already threatens the well-being and prosperity of people across the country. The costs aren't limited to those affecting economic prosperity; while climate change impacts to cultural and ecological values cannot be monetized, they threaten the basis of what sustains and defines Canada. Every sector of the economy, every community, and every household is either directly or indirectly at risk.

Even though experts currently understand only the tip of the iceberg of climate-related costs, these alone should be enough to trigger a course correction. The large and growing costs of insured losses, emergency response, and recovery from weather-related disasters are an important indication of how a changing climate is already impairing Canadian society and the economy.

Looking forward, Canada could face much higher and more pervasive costs, both in terms of disasters and other impacts, than those experienced so far.

The bad news is that climate change adaptation in Canada is far behind where it needs to be. Progress has been slow, held back in part by a lack of understanding about the risks and costs of climate change. This uncertainty makes it difficult to decide which climate risks should be the focus of limited resources.

However, even where there is a solid understanding of impacts, action is not occurring at the scale that is required to adapt and plot a pathway to a climate-resilient future. Better information is required, without doubt—but better action is also needed, based on what is already known.

Governments, businesses and communities must get serious about putting adaptation policies and practices into place now, while better identifying the physical and social climate risks threatening well-being and future prosperity. The following policy recommendations provide a starting point:

1 All orders of government should significantly scale up public funding for implementing adaptation.

A lack of foresight on climate change risks should not be a barrier to significantly scaling up adaptation investment. Addressing climate-related risk and building resilience implicates many, if not most, government activities and programs. Successful implementation therefore requires not only dedicated government capacity and expertise on adaptation, but mechanisms to integrate and fund adaptation in existing government programs and public investments, including infrastructure, health care, Indigenous affairs, Northern programs, economic development, energy, public safety, natural resource management, and environmental protection. To drive this change, government programs and investments should transparently evaluate their effects on current and future climate risks, and the costs and benefits of incorporating adaptation and resilience. As our analysis shows, adaptation faces barriers to implementation, but returns multiple benefits.

2 The federal government should convene provincial, territorial, Indigenous and municipal governments to co-develop a more coordinated approach to governing adaptation.

The need to deploy adaptation at the scale and speed that Canada requires transcends administrative, geographic, and sectoral boundaries. Adaptation must be tailored and implemented at a local level to reflect local context. Yet coordination can reduce overlap, inconsistencies, and gaps. A coordinated, collaborative approach could set adaptation priorities, goals, and measures of progress, establish roles and responsibilities, identify policies that are essential for driving adaptation at all scales, and coordinate and leverage finance.

3 Governments and financial regulators should systematically enhance public disclosure and transparency of the economic and social implications of climate change risks across both the public and private sectors.

As the Task Force on Climate-Related Financial Disclosures and Canada's Expert Panel on Sustainable Finance have highlighted, transparency about climate change risks is essential for allocating investment away from risk and towards resilience. This extends beyond disclosure rules for large, publicly traded companies; it also includes increased transparency around the climate risks that governments, communities, and individuals face. Whether incorporated into government credit ratings or real estate home inspections, this information will help governments, firms, and individuals better prepare for a changing climate. It will also shift investments toward resilient solutions, galvanizing a range of adaptation actions.

Acting on these recommendations will require better insight and foresight into climate risks and costs, adaptation options, and the costs and benefits of these options. It will help drive demand for improved information to fill Canada's current knowledge gaps. The research the Canadian Institute for Climate Choices publishes over the next two years will help build a more reliable knowledge base. Along the way, we will engage stakeholders to gain additional insight on the costs of climate change and the types of information they require to act on adaptation. And we will also catalyze conversations about policy choices and investments that can help move adaptation priorities off the page and into practice across the country.

GLOSSARY

The definitions in this section reflect how key terms below are used in this paper and in the discipline of climate change adaptation research. Many terms here also have alternate meanings or application outside of climate-related contexts.

Adaptation	The ways in which human and natural systems adjust to reduce the harmful effects of climate-related changes and capitalize on the benefits.
Adaptive capacity	The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce negative impacts, moderate harm, or exploit beneficial opportunities resulting from climate change.
Attribution	Identifying how various factors contribute to an observed change or event, such as floods or storms.
Baseline (or reference)	The state against which change is measured. A "current baseline" represents observable, present-day conditions. A "future baseline" is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Catastrophic insured loss	An event that causes large insured losses. In Canada, these are currently defined as losses of $25 million or greater.
Climate	The average weather in a place over a long period of time, typically decades or longer.
Climate change	Changes in the usual climate of the Earth, predominantly caused by the burning of fossil fuels, which add heat-trapping gases to Earth's atmosphere. It manifests as overall global warming but also in sea-level rise, melting of previously permanent snow and ice, and more extreme weather.

Climate extreme (extreme weather or climate event)	The occurrence of a weather or climate variable (such as temperature) that falls above or below the upper or lower limits of observed values for that variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes'.
Climate model	A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and interannual climate predictions.
Climate projections	Estimates of the response of the Earth's climate to a range of plausible pathways, scenarios, or targets that capture the relationships between human choices, emissions, concentrations, and temperature change. Climate projections are distinguished from climate predictions to emphasize that there is major uncertainty associated with this range of plausible futures and that none can generally be predicted to be more likely than others.
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread negative human, material, economic, or environmental effects that require an immediate emergency response to satisfy critical human needs and may require external support for recovery. Disaster risk is the likelihood that a disaster will occur within a specified period.
Drought	A period of abnormally dry weather long enough to cause a serious shortage in the availability of water for natural ecosystems, agriculture, and human consumption.
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected by climate change.
Hazard	The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.
Heat wave	A period of temperatures that are higher than what is normally expected. Heat waves may span several days to several weeks.

Impacts	Effects on natural and human systems. In this report, the term "impacts" is used to refer to the effects on natural and human systems of physical events, of disasters, and/or of climate change.
Likelihood	An estimate of the probability of the occurrence of a single event or of an outcome (for example, a climate parameter, observed trend, or projected change within a given range). Likelihood may be based on statistical or modeling analyses, expert assessments, or other quantitative analyses.
Permafrost	Ground (soil, rock, ice, and organic material) that is frozen and remains at or below 0° C for at least two consecutive years, typically occurring in polar or near-polar regions.
Resilience	The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as probability of the 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. In this report, the term risk is used primarily to refer to the risks of climate change-related impacts.
Sensitivity	The degree to which an individual, asset, household, community, business, or ecosystem is affected, either adversely or beneficially, by climate variability or change.
Storm surge	The temporary increase in the height of the sea due to extreme weather conditions, including low atmospheric pressure and/or strong winds. The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, negative effects of climate change, including climate variability and extremes.

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